The techniques of quality operations computational and experimental researches of the launch vehicles in the drawing-board stage

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The techniques of quality operations computational and experimental researches of the launch vehicles in the drawing-board stage

K Rozhaeva

Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia

e-mail: rozhaevkse1na@gmail.com

Abstract. The aim of the research is the quality operations of the design process at the stage of research works on the development of active on-Board system of the launch vehicles spent stages descent with liquid propellant rocket engines by simulating the gasification process of undeveloped residues of fuel in the tanks. The design techniques of the gasification process of liquid rocket propellant components residues in the tank to the expense of finding and fixing errors in the algorithm calculation to increase the accuracy of calculation results is proposed. Experimental modelling of the model liquid evaporation in a limited reservoir of the experimental stand, allowing due to the false measurements rejection based on given criteria and detected faults to enhance the results reliability of the experimental studies; to reduce the experiments cost.

1. Introduction

In this study, at the stage of scientific research as the main characteristics of the object, which is included in its quality, the reliability criterion of scientific results is applied.

To assess the reliability of the research results is to establish the degree of closeness of numerical and experimental studies results. Taking into account such factors affecting the final result as: different conversion, assumptions and simplifications in the mathematical and physical models, using the wrong dimensions, human factors, external conditions the carrying out of the experiment, which lead to inaccuracy and various sorts of errors that require minimization.

The methods of ensuring the theoretical results reliability were used at the stage of research works by using known solutions for the process under study and the licensed software, that confirmed with experiments and a satisfactory convergence of the calculated and experimental data.

The analysis of the current level of theoretical and practical achievements in the field of quality operations in the early design stages of complex technical systems by Russian scientists: V. Vasil’ev, A. Akhtulov, A. Al’breht, D. Golovin, and foreign scientists: B. Anderson, V. Roshan Joseph, Harriet Black Nembhard, showed that there is a need for improved approaches, concepts and methodologies of quality operations theoretical and experimental studies, that is, the creation of the generalized characteristics of the research results, to evaluate their objectivity, depth, novelty and usefulness.
When creating the elements of space-rocket technologies, not having prototypes, the basic requirements to the system are in the formative stage, and appropriate research methods require additional refinement. Accordingly, the base for comparisons, as a rule, is absent, and respectively the probability of incorrect design decisions is large enough [6].

Thus, there is a need for experimental studies to substantiate the objectivity and reliability of the developed techniques of research and development based on that the technical specification for the next design stage will form, in particular, on the preliminary design.

The practical implementation involves considerable financial and time costs, so the minimization of error (methodological, mechanical and others) is extremely important.

2. Theory

When conducting theoretical and experimental studies of the functioning process of the active on-Board descent system is proposed to the systematize and adapt existing methods of error search for the task are proposed; use the system of reliability criteria of the obtained results (theoretical and experimental) at each stage of the research based on fundamental laws that identify methodological, technical dysfunctions in the preparation of mathematical and physical models; during theoretical and experimental research to provide parallelism for their comparability (e.g., in parallel with the experiment on the stand real to perform calculations in the computer using results from the physical measurements from the stand); in the preparation of mathematical and physical models with the introduction of assumptions into account to make this error; mandatory verification of the mathematical model.

Figure 1 shows the procedure algorithm for ensuring the quality of theoretical and experimental studies. The proposed techniques covers the mathematical and physical modelling, each of which presents a set of mechanisms to enhance the reliability of research results, which ultimately ensures the quality of design techniques of the real system.

During the equations integration of the mathematical model for the control of the current results, the criteria ensure the reliability of the results obtained based on respect for fundamental laws is used: the first law of thermodynamics, the second law of thermodynamics [7].

1. The temperature of the heat transfer is subject to the second law of thermodynamics showing the direction of the processes:

\[ T_{HC} \geq T_{gas} > T_{liq} > T_{plate} > T_{glass} > T_{steel}. \] (1)

where \( T \) is the temperature of the heat carrier, gas, plate, glass and steel walls of the experimental model stand.

Since the heat carrier has the highest temperature and is the only source of heat transfer.

2. The heat carrier thermal energy is equally distributed between the participants of heat transfer, according to the law of internal energy change of each participant:

\[ U_{HC} > U_{gas} > U_{liq} > U_{plate} > U_{glass} > U_{steel}, \] (2)

where \( U = c m \Delta T \) – is the internal energy of the heat transfer participants: heat carrier, gas, glass and steel walls.

3. According to the energy conservation law, all deposited energy of the heat carrier in an experimental model stand is consumed for the internal energy change of the heat transfer participants and between the participants:

\[ Q_{HC} = Q_{gas} + Q_{liq} + Q_{glass} + Q_{steel} + Q_{plate} - Q_{dr}. \] (3)

4. The gas pressure inside the experimental model stand should be more atmospheric:

\[ p_o < p(t) < p_o + \Delta p \] (4)

where \( p_o = 101325 \) Pa, \( \Delta p = \frac{G^2 + p}{2 \mu^2 + g} \).

5. There will be no the mass growth of the liquid inside the stand:

\[ \dot{m}_{liq_{max}} > \dot{m}_{HC} - \dot{m}_{dr} - \dot{m}_{liq} > 0 \] (5)

where \( \dot{m}_{HC} \) – the mass flow rate of the heat carrier, \( \dot{m}_{dr} \) – is the mass flow rate of the gas at the outlet of the stand, \( \dot{m}_{liq} \) – isterateofliquidevaporation.
The proposed criteria are the basic conditions of reliability of calculated results and allow us to judge the correctness of the mathematical model and the basis for the termination of simulation and search, elimination of mistakes in the calculation algorithm.

The term "gasification" is used in the development of active on-Board descent system of the launch vehicle spent stage, and the term "evaporation" – when the process modelling at the experimental stand.

The proposed techniques includes the following steps aimed at bringing into line the given conditions of experimental studies and evaluation criteria process [8-9].

1. We provide additional measurement of the heat carrier flow velocity in the characteristic points of the experimental model stand, gas humidity at the outlet of the experimental model stand and calculated based on the measurements the values of the total heat received by the plant size during the experiment according to the formula:

\[ Q_\Sigma^0 = c_{HC} \dot{m}_{HC} T_{HC} \tau, \]

where \( c_{HC} \) – is the heat carrier specific heat (a table value); \( \dot{m}_{HC} \) – is the measured heat carrier flow rate; \( T_{HC} \) – the measured temperature of the heat carrier, \( \tau \) – is the measured time of the experiment.

2. Calculated total value of heat spent for heating each object model of the experimental stand involved in the heat transfer during the experiment according to the formula:

\[ Q_\Sigma^* = Q_{gas} + Q_{liq} + Q_{plate} + Q_{glass}, \]

and compare the calculated values of \( Q_\Sigma^0 \) with \( Q_\Sigma^0 cQ_\Sigma^* \).

In the case of the condition implementation:

\[ |Q_\Sigma^0 - Q_\Sigma^*| \geq E_Q, \]

where \( E_Q \) includes instrumental and methodical errors, the results of the experiment admit the invalid, stop the experiment and identify faults in the measurement system and data logging.
3. In the experiment at the current time must be adhered to the second law of thermodynamics, to check used the temperature sensor, compares the temperature of the heat carrier $T_{HC}$ and $T_i$ elements of the experimental model stand:

$$T_{HC} \geq T_i, \quad i=1, \ldots, N,$$

(9)

where $N$ – is the number of installed temperature sensors inside the experimental model stand.

In case of conditions dysfunction (9) the experiment is terminated and the detected fault in the measurement system and data logging.

4. For steady state convective gasification of the liquid in which the gas temperature inside the

**Figure 1.** The algorithm of the techniques to ensure quality of theoretical and experimental studies.
experimental model stand is permanent $\frac{dT_{gas}}{dt} = 0$, sensors determined the gas temperature $T_{gas}$ and the gas pressure $p_{gas}$ inside the stand.

In case of adiabaticity conditions dysfunction $p_{gas}/T_{gas}$ the experiment is terminated and the detected fault in the measurement system and data logging.

5. Based on the measurements of relative gas humidity $\phi$ in the volume of the experimental model stand the experimental partial pressure at the gas temperature $T_{gas}$ in the experimental model stand is calculated:

$$p^* = \varphi p_{gv} \quad (10)$$

where $p^*$ – is the partial gas pressure in the experimental model stand; $p_{gv}$ – is the gas vapour pressure in the experimental model stand, which is calculated in accordance with the actions.

Received the partial gas pressure in the experimental model stand is compared to the table $p^0_p$, defined in accordance with the actions:

$$|p^0_p - p^*| \geq E_p \quad (11)$$

where $E_p$ includes instrumental and methodical imprecisions.

In case of conditions dysfunction (11) the experiment is terminated and the detected fault in the measurement system and data logging.

3. Discussion

Proceeding from the above, achieved the following results:

- Due to rejection of invalid measurements and the time-detected faults increases the accuracy of research results;
- Timely detected fault;
- Reduces the cost of experiments.

Energy costs are decreased by 20-25%. This reduced work time consumption. Reduced labour cost due to:

- The termination of the "gas-liquid" system experiment when the temperature becomes stationary;
- Reducing the time of preparation of the heat carrier (the heating time to a predetermined temperature) due to the insulation of the electric heater, and connecting fittings.

Thus, the proposed quality ensure techniques of research can significantly improve the accuracy of the results.

4. Conclusion

The use of the proposed techniques of quality ensure the experimental studies on early stages of design to avoid a number of methodological (mathematical model), algorithmic (the compilation of algorithm and program of calculation) and mechanical errors (use of incorrect values of physical constants, dimensions, and other mechanical errors in the preparation of the initial data).

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