DOI: https://doi.org/10.15407/pmach2023.04.017

UDC 539.3

# STRENGTH OF COMPOSITE TRANSPORT AND LAUNCH CONTAINER FOR ROCKET LAUNCH

[1] **Kostiantyn V. Avramov**
kvavramov@gmail.com, ORCID: 0000-0002-8740-693X

[2] **Volodymyr M. Sirenko**
v.n.sirenko@i.ua, ORCID: 0000-0002-8152-2358

[2] **Volodymyr V. Zaverukha**

[3] **Sergiy I. Plankovskyy**
sergiy.plankovskyy@kname.edu.ua, ORCID: 0000-0003-2908-903X

[3] **Yevgen V. Tsegelnyk**
y.tsegelnyk@kname.edu.ua, ORCID: 0000-0003-1261-9890

[3] **Volodymyr V. Kombarov**
ORCID: 0000-0002-6158-0374

[1] Anatolii Pidhornyi Institute of Mechanical Engineering Problems of NAS of Ukraine
2/10, Pozharskyi str., Kharkiv, 61046, Ukraine

[2] Yuzhnoye State Design Office
3, Krivorizka St., Dnipro, 49008, Ukraine

[3] O.M. Beketov National University of Urban Economy in Kharkiv, 17, Marshal Bazhanov str., Kharkiv, 61002, Ukraine

*A transport and launch container for launching rockets made of fiberglass is considered. The main goal of the paper is to calculate the stress state of this container and check the strength conditions. The calculation of the pressures of the combustion products is carried out for several positions of the rocket nozzle in the container. Two cases are considered for the nozzle, which is located: in the middle of the container and at the outlet of the container. The maximum values of the pressure acting on the inner side of the container are observed when the rocket nozzle exits the container. The pressure field is axisymmetric. In view of this, to approximate the pressure field, it is decomposed into a Fourier series along the longitudinal coordinate of the rocket. The stress state of the container is also axisymmetric. In addition, it is also considered for two cases of the nozzle and the container configuration. The finite element method implemented in the ANSYS software complex was used to calculate the stress state. The highest stress values are observed when the nozzle exits the container. As it follows from the finite element calculations, circumferential stresses are the greatest. The strength limit of fiberglass is used to analyze the strength of the container. As can be seen from the calculations, the container meets the strength requirements with a large margin factor.*

***Keywords**: aerodynamic load, stressed state, rocket launch, composite material.*

## Introduction

The transport and launch container is used to launch rockets, which can be carried out from a car. In addition, the rocket launch is also possible from a subsonic mothership aircraft. The main purpose of the transport and launch container for launching a rocket from a car is storage, transportation of the rocket and its launch, and during the launch of the rocket from the mothership aircraft - the exclusion of mechanical shock effects on the rocket, thermal and electromechanical effects, launch and transportation of the rocket. In addition to the above, the transport and launch container is also used to launch rockets by police officers for humanitarian purposes [1].

The transport and launch container is a composite guide tube. During its design, the calculations of the following factors should be made [2, 3]:

1) shock wave and gas dynamic loads acting on the transport and launch container by numerical methods of gas dynamics;

2) the strength of the composite body of the transport and launch container, which should ensure the rocket launch and protect the rocket from lateral overloads.

Fiberglass was used for the container production. Much effort has been devoted to the study of the mechanical characteristics of fiberglass. They are discussed in detail in papers [4–7].

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This paper describes the method of the composite rockets transport and launch containers strength calculation based on the ANSYS software complex. The loads acting on the container are determined from the gas dynamic calculation, which is also presented in this paper. Conclusions about the strength of the fiberglass container were drawn.

## Calculation of aerodynamic loads

The results of numerical modeling of the leakage of a supersonic jet into the semi-closed space of the launch tube (cylindrical tube) are considered. According to the results of this calculation, the gas flow parameters along the tube are studied depending on the relative sizes of the nozzle and the tube, as well as thermodynamic and gas dynamic characteristics of the supersonic jet. The gas dynamic flow is axisymmetric and does not depend on the circumferential coordinate.

The parameters of the gas dynamic calculations were chosen as follows: Mach number is $M_a$=2.5–3; non-nominal value is $n=p_a/p_\infty=3.5$; relative elongation of the tube is $L/D$=25 the gap between the tube and the rocket is $D/D_1$=1.004, where $L$, $D$ – length and diameter of the tube; $D_1$ – rocket diameter; $p_\infty$ – atmospheric pressure.

Fig. 1 shows the values of the absolute static pressure distribution on the inner wall of the tube at the time of the rocket exiting the tube, depending on the relative elongation of the tube.

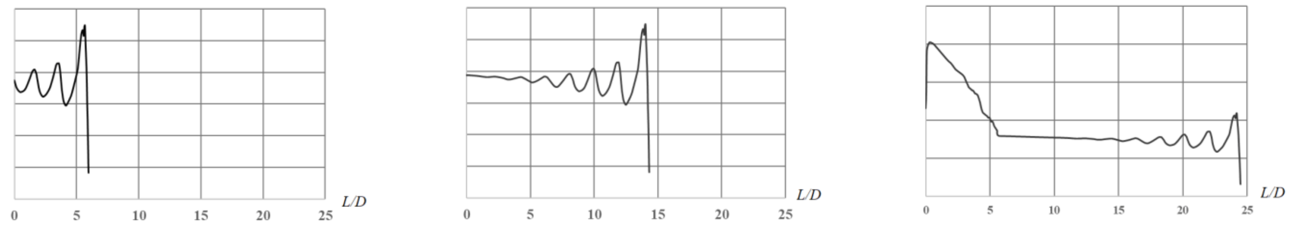


*Fig. 1. Pressure on the inner wall of the tube*

The results show that a wave-like structure is formed. It is characteristic of the jet flowing into the semi-closed space of the tube. Downstream, the parameters on the tube walls have peculiarities depending on the tube length. It can be seen that the first zone with the maximum value is formed at a distance of (1–1,2)×$D_a$, where $D_a$ – nozzle diameter; the second zone is on the lower part of the tube.

Based on the obtained results, it is possible to propose the following formula for calculating the pressure on the inner wall of the tube in the nozzle area: $P = 1.5 \cdot n \cdot p_\infty$.

The maximum values of the pressure on the inner wall of the tube at the moment the rocket exits the container are calculated as follows: $P_{\max} = 3 \cdot n \cdot p_\infty$.

Let's construct an approximation of the pressure distribution acting on the inner wall of the container. To do this, we derive a fairly accurate function approximating the pressure distribution (Fig. 1). For the case of the nozzle completely exiting the tube, this function consists of five piecewise linear sections. This function is marked by bold lines on Fig. 2. Approximation of pressure depending on the longitudinal coordinate of the container $x$ can be imagined as follows:

$$P(x) = \begin{cases} a_0 x + b_0;\ x_0 < x < x_1 \\ a_i x + b_i;\ x_i < x < x_{i+1};\ i = 1, \ldots, 4 \end{cases}. \tag{1}$$

Some parameters of expansion (1) are as follows: $x_0=b_0=a_2=0$; $x_5=L$. Other parameters acquire the following values:

$$\begin{gathered} x_1=0.06;\quad x_2=1.1;\quad x_3=4.5;\quad x_4=4.8;\quad L=5\text{ m}; \\ a_0=16.67;\quad a_1=-0.577;\quad a_3=0.5;\quad a_4=-2.75\text{ MPa/m}; \\ b_1=1.0347;\quad b_2=0.4;\quad b_3=-1.85;\quad b_4=13.75\text{ m}. \end{gathered} \tag{2}$$

Bold line in Fig. 3 indicates the approximation of the pressure distribution acting on the container if the rocket nozzle is located in the middle. This approximation consists of five piecewise linear sections, which is well described by (1). The parameters of relation (1) are as follows:

$$x_0=0;\quad x_1=0.01;\quad x_2=0.7;\quad x_3=2.24;\quad x_4=2.62;\quad x_5=2.7\text{ m};$$
$$a_0=300;\quad a_1=-0.2898;\quad a_2=-0.026;\quad a_3=0.368;\quad a_4=-2.5\text{ MPa/m};\qquad (3)$$
$$b_0=0;\quad b_1=0.303;\quad b_2=0.1182;\quad b_3=-0.76;\quad b_4=6.75\text{ m}.$$

We will use the ANSYS package for strength calculations. In this package, the pressure approximation (1) is extremely difficult to implement. It is much easier to apply pressure expansion (1) in the Fourier series:

$$P(x)=\frac{a_0}{2}+\sum_{n=1}\left[a_n\cos\left(\frac{2n\pi x}{L}\right)+b_n\sin\left(\frac{2n\pi x}{L}\right)\right].\qquad (4)$$

Expansions (4) are indicated by a thin solid line in Figs. 2, 3. 20 harmonics of the Fourier series are present in these expansions. These lines are extremely close to the bold lines that show the approximations (1).

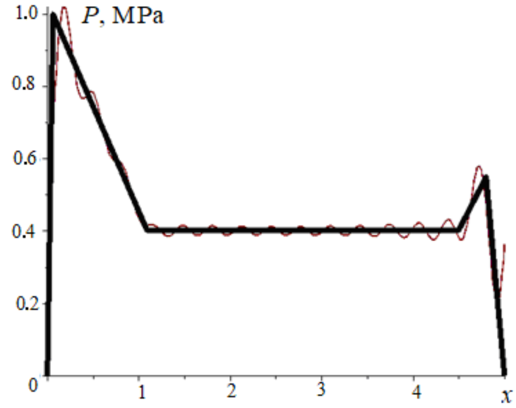


*Fig. 2. Approximation of the pressure on the container when the nozzle exits the tube*

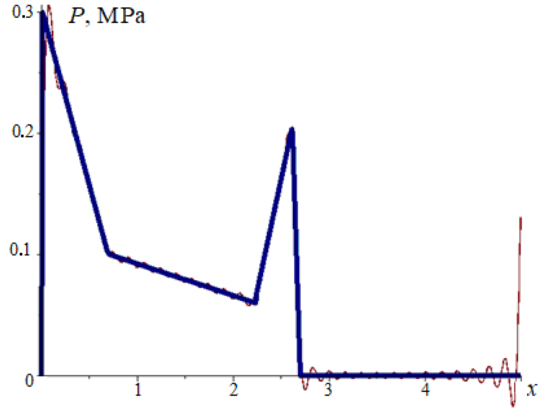


*Fig. 3. Approximation of the pressure on the container when the nozzle is located in the middle of the tube*

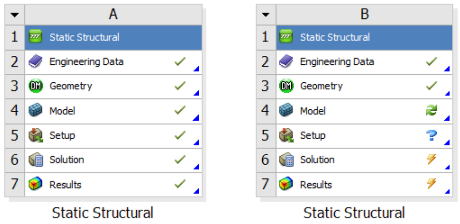
## Stress state of the container

We will consider the stress state of the container in the cylindrical coordinate system. $x$ coordinate is placed in the longitudinal direction of the cylindrical tube; φ coordinate – in the circumferential direction, and $z$ coordinate – in the radial direction.

The mechanical characteristics of fiberglass were chosen as follows [4–7]: Young's moduli $E_\varphi=2.69\times10^9$ Pa; $E_x=2.2\times10^9$ Pa; shear moduli $G_{x\varphi}=4.07\times10^9$ Pa; $G_{\varphi z}=G_{xz}=5.0\times10^9$ Pa; Poisson's ratios $\nu_{x\varphi}=0.11$; $\nu_{\varphi z}=\nu_{xz}=0.3$.

A fiberglass container in the form of a cylinder has the following geometric dimensions: length $L$=5 m; diameter $D$=20 cm; thickness $h$=6 mm.

The pressure acting on the container from the inside is axisymmetric, therefore the stress state will be axisymmetric. The calculation of the fiberglass container stress state is carried out under the action of gas dynamic pressure, presented in Figs. 2, 3, in the ANSYS software complex. Its Static Structural calculation module was used. The method of summoning the main subroutines of this block is shown in Fig. 4. The preprocessor of the Geometry program is shown in Fig. 5.



| | A | |
|---|---|---|
| 1 | Static Structural | |
| 2 | Engineering Data | ✓ |
| 3 | Geometry | ✓ |
| 4 | Model | ✓ |
| 5 | Setup | ✓ |
| 6 | Solution | ✓ |
| 7 | Results | ✓ |

Static Structural

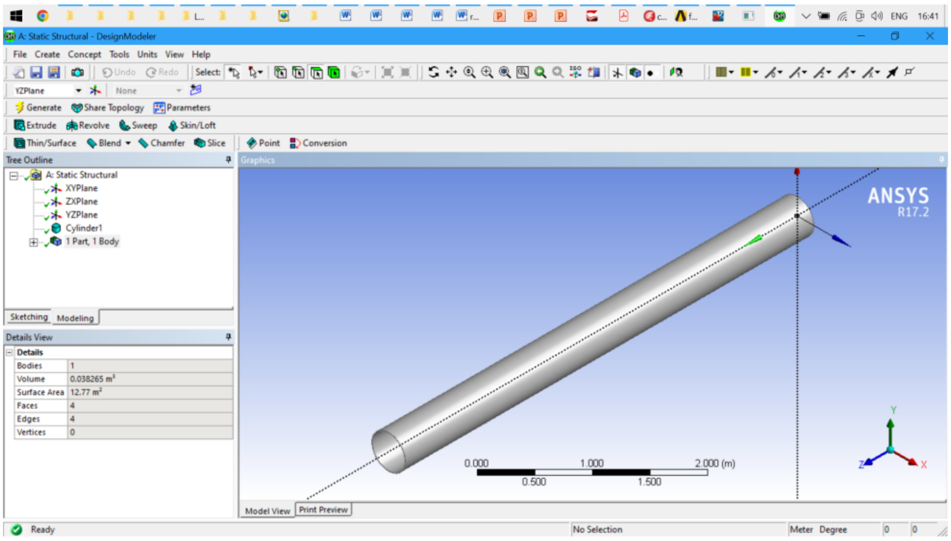
| | B | |
|---|---|---|
| 1 | Static Structural | |
| 2 | Engineering Data | ✓ |
| 3 | Geometry | ✓ |
| 4 | Model | ⟳ |
| 5 | Setup | ? |
| 6 | Solution | ⚡ |
| 7 | Results | ⚡ |

Static Structural

*Fig. 4. Working panel of the Static Structural module*

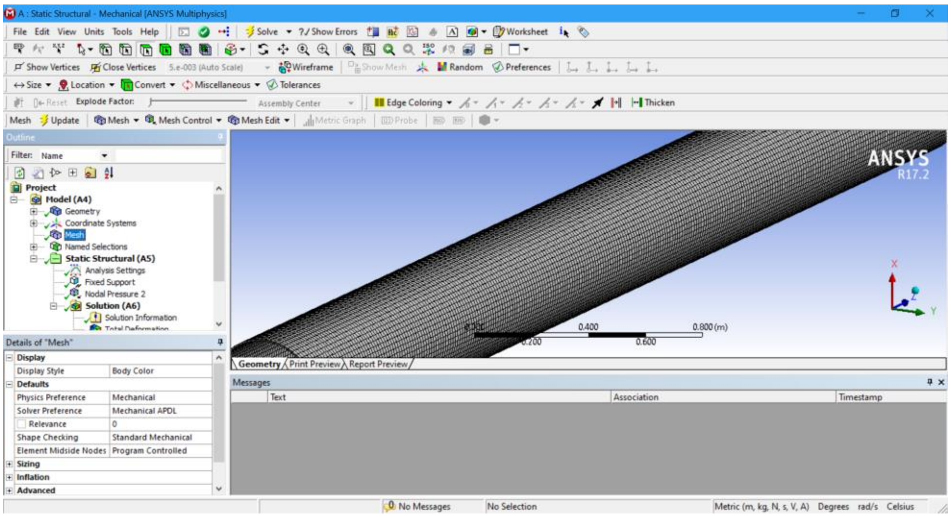
The shell of the Model preprocessor is shown in Fig. 6. This figure also shows the finite element grid of the structure.

The results of the calculation of the equivalent stresses in the container body are shown in Figs. 7, 8. So, Fig. 7 shows the equivalent stresses in the body of the composite container, which arise under the action of aerodynamic pressure (Fig. 2), and in Fig. 8 – equivalent stresses in a fiberglass container arising as a result of aerodynamic pressure (Fig. 3).



| Details | |
|---|---|
| Bodies | 1 |
| Volume | 0.038265 m³ |
| Surface Area | 12.77 m² |
| Faces | 4 |
| Edges | 4 |
| Vertices | 0 |

*Fig. 5. Geometry subroutine preprocessor*



Details of "Mesh"

| Display | |
|---|---|
| Display Style | Body Color |
| **Defaults** | |
| Physics Preference | Mechanical |
| Solver Preference | Mechanical APDL |
| ☐ Relevance | 0 |
| Shape Checking | Standard Mechanical |
| Element Midside Nodes | Program Controlled |
| **Sizing** | |
| **Inflation** | |
| **Advanced** | |

*Fig. 6. Model subroutine preprocessor*

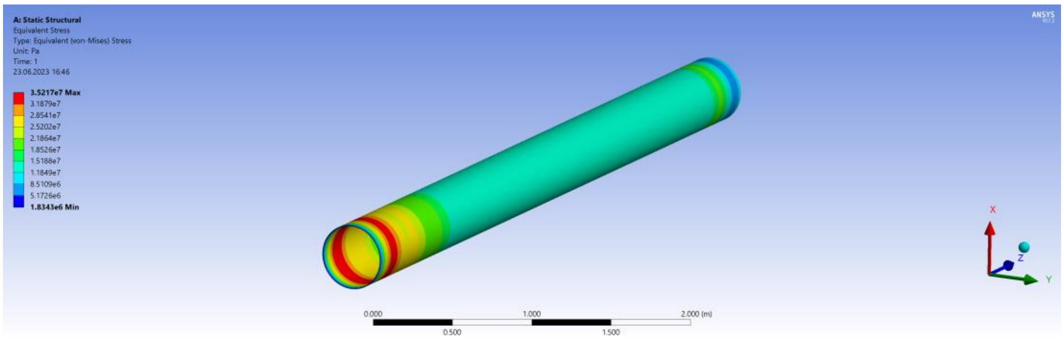


*Fig. 7. The distribution of equivalent stresses in the container under the influence of aerodynamic pressure presented in Fig. 2*

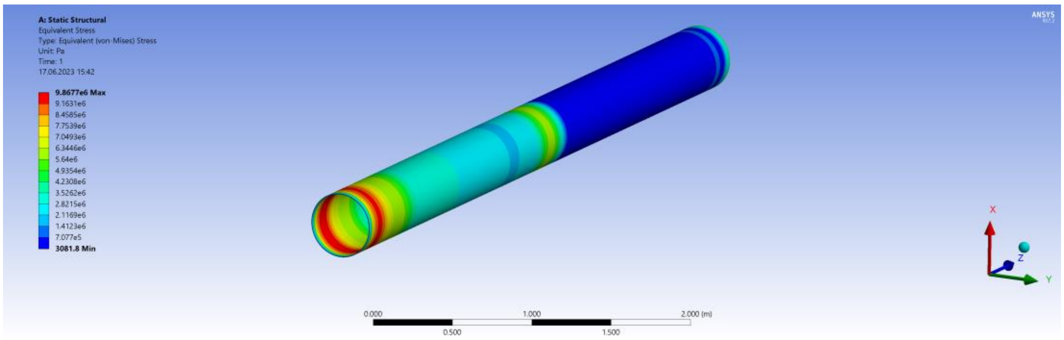


*Fig. 8. The distribution of equivalent stresses in the container under the influence of aerodynamic pressure presented in Fig. 3*

Now we will evaluate the static strength of the container. According to [6], the strength limit of fiberglass is equal to $\sigma_*=1\times10^8$ Pa. The maximum equivalent stresses arising in the structure (Fig. 4, 5) are equal to $\sigma_e=9.8\times10^6$ Pa; $\sigma_e=3.5\times10^7$ Pa.

## Conclusions

The option of the transport and launch container made of composite material (fiberglass) was considered. A methodology for calculating the stress state of such a container, which consists of two stages, is proposed. At the first stage, the aerodynamics of the combustion products coming out of the rocket nozzle and moving through the tube are modeled. As a result of this simulation, the pressure field acting on the inner wall of the container is determined. At the second stage, a computer simulation of the stress state of the container under the influence of the calculated pressure field is carried out.

To calculate the stress state of the container, it is suggested to use the ANSYS software package. Based on the results of the stress state calculations, it was concluded that the fiberglass container with the proposed geometric parameters meets the strength criteria with a large margin factor.

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*Received 08 November 2023*

# Міцність композитного транспортно-пускового контейнера для старта ракети

**[1] К. В. Аврамов, [2] В. М. Сіренко, [2] В. В. Заверуха,**
**[3] С. І. Планковський, [3] Є. В. Цегельник, [3] В. В. Комбаров**

[1] Інститут проблем машинобудування ім. А. М. Підгорного НАН України,
61046, Україна, м. Харків, вул. Пожарського, 2/10

[2] Державне підприємство «Конструкторське бюро «Південне» ім. М. К. Янгеля»,
49008, Україна, м. Дніпро, вул. Криворізька, 3

[3] Харківський національний університет міського господарства імені О. М. Бекетова,
61002, Україна, м. Харків, Маршала Бажанова, 17

*Розглядається транспортно-пусковий контейнер для старту ракет із склопластику. Основною метою статті є розрахунок напруженого стану цього контейнера й перевірка умов міцності. Розрахунок тисків продуктів згоряння проводиться для декількох положень сопла ракети в контейнері. Розглядаються два випадки: коли сопло знаходиться посередині контейнера і на виході з контейнера. Максимальні значення тиску, що діє на внутрішній бік контейнера, спостерігаються при виході сопла ракети з контейнера. Поле тисків є осесиметричним. З огляду на це для апроксимації поля тиску воно розкладається в ряд Фур'є за поздовжньою координатою ракети. Напружений стан контейнера також є осесиметричним. Крім того, він також розглядається для двох випадків взаємного розташування сопла і контейнера. Для розрахунку напруженого стану використовувався метод скінченних елементів, який реалізовано в програмному комплексі ANSYS. Найбільші значення напружень спостерігаються під час виходу сопла з контейнера. Як випливає із скінченно-елементних розрахунків, найбільшими напруженнями є окружні. Для аналізу міцності контейнера використовується межа міцності склопластику. Як видно з розрахунків, контейнер задовольняє умовам міцності з великим коефіцієнтом запасу.*

***Ключові слова**: аеродинамічна навантаження, напружений стан, старт ракети, композитний матеріал.*

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