RBFTA Revista Brasileira de Física Tecnológica Aplicada

Revista Brasileira de Física Tecnológica Aplicada
ISSN: 2358-0089

https://periodicos.utfpr.edu.br/rbfta

Impacts of the spill hole in the stability of a model rocket parachute

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ABSTRACT

Rocketry is a practice that has been growing in Brazil, especially within universities. One of the major challenges in this activity is the recovery system, responsible for ensuring a safe descent of the rocket. This study aimed to analyze the efficiency of a scale parachute, using a wind tunnel to compare the obtained data with that found in the literature. The influence of the spill hole diameter was examined by utilizing a device with 5% and 10% diameter relative to the total parachute diameter, assessing its impact on stability during descent. Based on this, the experiments were conducted using scale models in a wind tunnel at the Federal University of Minas Gerais, maintaining ambient conditions for both models. The results of the tests indicated that the parachute with a larger spill hole had significantly better stability, with less variation in drag force. The 5% parachute exhibited a standard deviation in drag force values 3.9 times greater than the 10% parachute (at a flow velocity of 25 m/s). The findings suggest an increase in the parachute's drag coefficient with a smaller canopy opening, resulting in higher drag force.

KEYWORDS: spill hole; parachute stability; drag forces

INTRODUCTION

In 2019, according to a research conduct by the Aeroespace Development Group of the Federal University of Ceará (GDAe-UFC), there were 123 rocketry teams affiliated to educational institutions in Brazil. The region with the largest number of teams was the South region, with 54. The South and Southeast regions represented 75% of the teams in the country. Of the total, 80% of the teams are linked to a higher education institution and 61% of all teams are part of a public university.

Aerospace science is not yet widely disseminated in Brazil, although it attracts the attention of many people. The high capital expenditure (CAPEX) required for aerospace development is one of the causes. The primary equipment used in this field, the wind tunnel, is an example of equipment with a high acquisition cost. The 'Amarelão' wind tunnel, at the Aeronautics Institute of Technology, was inaugurated in the city of São José dos Campos, a significant technological hub in Brazil, in 2003. The total investment amounted to 2.8 million dollars, with support from the São Paulo Research Foundation, FAPESP, and Embraer (FAPESP, May 2003). Despite the high capital required for aerospace development, the investment yields significant results. The sector is strategic for national defense. Moreover, Embraer holds the position of the third-largest manufacturer of commercial aircraft in the world and the largest producer of executive jets (CARVALHO, 2023), a feat that could not be possible without heavy investment in aerospace science.

One of the main challenges in the project of a rocket is the recovery system. In 10 out of the 11 launches of the Thunder rocket family, produced by GDAe-UFC, there were complications and the system did not work as expected. Particularly, a remarkable difficulty in improving the recovery system for this type of rocket is the high launching costs, making a true launch test unfeasible for university teams (NEWLANDS, 2014).

A way to improve the parachute performance is to add a spill hole, which consists of a circular projection hole at the top of the canopy with the aim of making the rocket’s descent more stable. This occurs because the spill hole allows the air flow to pass by the hole in the top of the parachute, decreasing the pressure inside the canopy and preventing air from swirling from one side of the fabric to the other. However, the exact effects of this device are not yet so well known and deserve to be studied in depth (CANNON; GRIMM, 1999).

Even though the use of spill holes is common today, suggesting that its effectiveness is known, there is a lack of studies comparing parachutes with different holes diameters, aiming to experimentally analyze its efficiency and degree of impact in the stability during the descent. In other words, it is known that the device works, but the question on how well it works is still unknown.

The general purpose of this work is to analyze these two scale model parachutes and verify the influence of the spill hole diameter in the stability, using a hole with a diameter equals to 5% of the total parachute diameter and another parachute with 10% spill hole diameter.

Given the operational unfeasibility of testing the recovery system during a true flight, two scale model parachutes were created, making it possible to test the system in a wind tunnel, using a strain gauge to measure the drag force.

LITERATURE REVIEW

The parachute, whose operating principle is based on the aerodynamic drag, aims to reduce the falling speed, reaching a state of equilibrium of forces, with a falling speed as close as possible to be constant and stable. The drag force F_d is defined by Fox, Pritchard, and McDonald (2014) as the component of a force that acts parallel and opposite to the relative motion with respect to the fluid and can be calculated by **Equation 1**:

$$F_D = \frac{1}{2}\rho . V^2 . A . C_D \tag{1}$$

Where V represents the flow speed, A is the parachute circular projection area perpendicular to the flow, ρ represents the density of the air and C_d is the drag coefficient, a dimensionless number associated with the body shape, usually determined experimentally (NASA, 2023). The **Equation 1** is useful to define the necessary area that the parachute must have to maintain an adequate descent speed.

Given the impracticality of testing the real Thunder XI parachute in the tunnel, due to wind tunnel size issues, it was necessary to create a scale model, respecting the wind tunnel blockage factor. So that the flow regime can be considered similar, two criteria need to be met: the two objects must be geometrically similar, what is guaranteed in this case, as the model is a scale copy of the real parachute; and the similarity parameter must be the same for both model and real body (ANDERSON, 1988). The parameter of Reynolds number can characterize a flow regime, in which the higher this number, the more turbulent the flow will be (FOX; PRITCHARD; MCDONALD, 2014). The Reynolds number (Re) can be defined by the **Equation 2:**

$$Re = \frac{DV\rho}{\mu} \tag{2}$$

Where D is the object diameter, V is the flow speed, ρ is the fluid density and μ is the dynamic viscosity of the same fluid.

As mentioned above, the **Equation 1** is used to calculate the correct size of the parachute, aiming to reach the final falling speed of 5 m/s. This speed is considered the ideal landing speed for an experimental rocket, in order to avoid any damage during the landing (NEWLANDS, 2014). The shape of the parachute may not have as much impact on its functioning and effectiveness. However, the semi-ellipsoidal shape used in this design is more efficient, achieving the expected drag force using less fabric (NAKKA, 2020).

Another important point to be considered in a rocket recovery system is the snatch load, defined as the main parachute deploying force, which can be two to three times stronger than the drag force experimented by the parachute during the final descent speed (HEANEY, 2022).

However, according to Heaney (2022), this force is more critical when the recovery system uses, in addition to the main parachute, a pilot one, which is a smaller parachute, opened shortly after the apogee, responsible for stabilizing the rocket's descent at high speed. This makes it possible to reduce the horizontal distance that the rocket travels due to the influence of the wind, pulling out the main parachute at the right time. This results in a stronger deceleration and, consequently, a larger load on the main parachute and its cords.

Despite that, in the situation of the Thunder rocket, there is just one parachute, that it is deployed right after the apogee. Assuming that the vertical speed in the apogee is zero, the snatch load will not be considered.

PARACHUTE SIZING

To size the parachute, it is necessary to understand the flight condition of the rocket model. Typically, small rockets fly at altitudes below 1 km. In the case of the rocket of interest to GDAe-UFC, the Thunder XI, it reaches an apogee of about 400 to 500 m. Therefore, the impact of altitude on the physical parameters of the air is negligible for the parachute.

The launches of the group's rockets are carried out at the experimental farm of UFC, located in the municipality of Pentecoste, Ceará. The city has an average temperature between 26 to 28 °C, according to the Regulatory Agency of the State of Ceará (2021). Being a rural region, the area has a lower incidence of wind. In addition, the city is located about 60 meters above sea level.

The Thunder XI rocket has a total mass, including all systems, engine, and fuel, of 4.384 kg. As mentioned earlier, the ideal descent speed for the rocket is 5 m/s. The adopted drag coefficient was found in the literature, according to Rick Newlands (2014, p.12) and it is presented in the **Figure 1**:

Figure 1 – Typical drag coefficient values

Type	Drag Coef. C_{D_0} Range	Opening Load Factor C_X (Inf. Mass)
Flat Circular	**.75 to .80**	**~1.8**
Conical	**.75 to .90**	**~1.8**
Cross	**.60 to .78**	**~1.2**
Flat Ribbon	**.45 to .50**	**~1.05**
Conical Ribbon	**.50 to .55**	**~1.05**

Source: Rick Newlands (2014, p.12).

For the parachute used in this study, the flat circular projection type was adopted, with a drag coefficient C_d range between 0.75 and 0.80. This coefficient can also vary due to the spill hole, and for the calculations in this work, a C_d value of 0.78 was adopted. Considering that the rocket must descend at a constant speed, there needs to be dynamic equilibrium between the drag force and the weight force. Thus, we have:

$$F_d = W \tag{3}$$

$$\frac{1}{2}\rho\, V^2 A\, C_d = m\, g \tag{4}$$

$$\frac{1}{2} \times 1.225 \times 5^2 \ \times \ A \times 0.78 \ = 4.384 \times 9.81 \tag{5}$$

which yields A = 3.60 m^2. Considering the parachute projection as a circle, it can be observed that its diameter is:

$$\frac{\pi}{4} d^2 = A \tag{6}$$

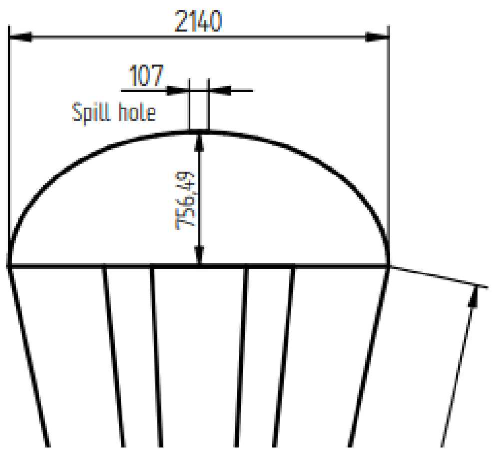
$$d = 2.14\, m \tag{7}$$

There is a space limitation according to the dimensions of the wind tunnel. It is important to note that the flow is influenced by the walls of the wind tunnel. Thus, it was established that the maximum diameter of the scaled parachute would be 50 cm. To maintain a scale within integers, a 1:5 ratio was adopted. Thus:

$$d_{(scale)} = \frac{1}{5} 2.14\, m = 42.8\, cm \tag{8}$$

After completing the sizing calculations for the system, the construction of the parachute was initiated. The practical aspect of construction, namely the sewing, is not the focus of this study. As the chosen parachute was semi-ellipsoidal, commonly used for this type of application, the guidelines from Richard Nakka's material (2020), a reference in model rockets, were followed. The chosen aspect ratio between the dimensions of the parachute was *b/a* = 0.707, where *b* represents the height of the parachute, and *a* represents the radius. This ratio provides a better distribution of structural stress across the canopy (NAKKA, 2020).

Figure 2 – Parachute dimensions (5% spill hole)



Source: Own authorship.

For the test parachutes, it is important to note that a 1:5 scale was used for all dimensions. Additionally, two different spill hole dimensions were employed. Parachute 1 has the mentioned device with a diameter equivalent to 10% of the total parachute diameter. On the other hand, Parachute 2 featured a spill hole with a diameter equivalent to 5% of the total diameter.

TEST PARAMETERS

To ensure that the tested models accurately depict reality, it is necessary for there to be similarity between the actual flow and the flow within the wind tunnel, as described earlier. Initially, the Reynolds number was calculated for the real parachute situation using **Equation 2**. The values for velocity *V* and diameter *D* used in the equation were those defined in the "Specific Basis for Parachutes" section and **Equation 8**, respectively. As for the values of ρ (density) and μ (viscosity), the standard atmosphere condition was considered, with the values taken from Coelho (2016) and presented in **Table 1**:

Table 1 – Parameters of the test

Parameter	Notation	Value
Density	ρ	$1.225\ \frac{kg}{m^3}$
Dynamic viscosity	μ	$1.79\ 10^{-5}\ \frac{N.s}{m^2}$
Flow velocity	V	$5\frac{m}{s}$
Diameter (real parachute)	$D(real)$	$2.14\,m$
Diameter (scale parachute)	$D(scale)$	$0.43\,m$

Source: own authorship.

Thus, using the **Equation** 2, we have:

$$Re = \frac{2.14 \times 5 \times 1.225}{1.79 \times 10^{-5}} = 732262.57 \tag{9}$$

Therefore, to ensure similarity between the flows and represent the real situation at scale, the Reynolds number was kept constant. Since the air properties involved in the Reynolds equation (density and dynamic viscosity) are similar in both the real parachute situation and the scaled parachute, with only the diameter varying, a modification in velocity is required to maintain similar flow. Thus, we have:

$$Re = \frac{0.43 \times V \times 1.225}{1.79 \times 10^{-5}} = 732262.57 \tag{10}$$

Isolating the velocity, we have:

$$V = \frac{732262.57 \times 1.79 \times 10^{-5}}{0.43 \times 1.225} = 24.88\ \frac{m}{s} \tag{11}$$

Thus, the required velocity in the wind tunnel to maintain the characteristics of the real flow is 24.88 m/s. For parameterization in the wind tunnel, an integer scale was adopted.

Initially, a 20 kg load cell was intended for use, allowing for a wide range of speeds during the test. However, during the experiment, the 20 kg load cell malfunctioned and was replaced with a 5 kg load cell. Despite the test being conducted at three speeds, 40 measurements were taken at each speed, totaling

120 measurements for each parachute. This represents a significant sample size. The **Table 2** shows the selected speeds:

Table 2 - Speeds at each measurement point

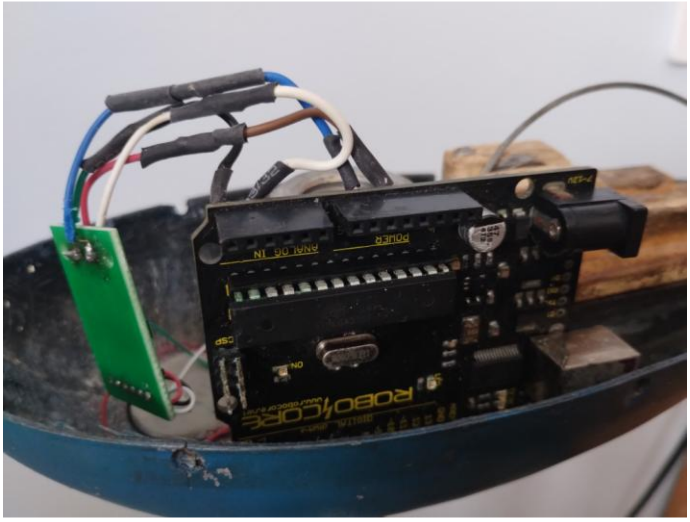
Measurement point	Speed (m/s)
Point 1	15 m/s
Point 2	17 m/s
Point 3	25 m/s

Source: own authorship.

INSTRUMENTATION

For the acquisition of the primary data, the drag force, a 5kg load cell (49.05N) was utilized. The load cell was connected to the HX711 amplifier converter module, which converts the analog signal into digital. The module is then connected to the Arduino UNO, which receives information from the load cell and transmits it via cable to a computer, displaying it on the serial monitor of the Arduino development interface, and also storing the data in a spreadsheet.

Figure 3 – Arduino board and HX711 amplifier



Source: own authorship.

The technical specifications of the 5kg load cell that influence the accuracy of the experiment are:

- Rated output: 1.0 ± 0.1 mV/V
- Nonlinearity: 0.08% FS
- Hysteresis: 0.1% FS
- Repeatability: 0.05% FS
- Creep (5 min): 0.05% FS
- Temperature effect on outputs: 0.02% FS/°C

- Temperature effect on zero: 0.02% FS/°C

Some of the wind tunnels in Brazil include those at the State University of Ceará (UECE), the Federal University of Minas Gerais (UFMG), the University of São Paulo (USP São Carlos), the Institute of Technological Research (IPT-São Paulo), the Institute of Aeronautics and Space (IAE), and the Aeronautics Institute of Technology (ITA). The chosen wind tunnel for the tests was the UFMG wind tunnel. The test section has an octagonal profile with a height of 1.00 meter and a width of 1.20 meters. The tunnel is a closed-circuit, atmospheric tunnel, reaching Reynolds numbers of up to 1.5 million for a 3D object.

The parachute cords are attached to a metal rod, which, in turn, applies force to the load cell.

Figure 4 – Metal rod system inside the wind tunnel

Source: own authorship.

DATA ANALYSIS METHODOLOGY

The data were collected using the aforementioned system. These data can be monitored in real-time using the serial monitor or stored in a spreadsheet. In this study, the drag force data measured by the load cell were recorded in a spreadsheet. The spreadsheet records the elapsed time in seconds since the start of the experiment and the drag force. Thus, to determine the fluid velocity at the time of each force measurement, the elapsed time at each speed was recorded.

The Arduino code performs data acquisition at half-second intervals. For each speed, data were recorded for 20 seconds, resulting in 40 measurements at each speed. This approach led to multiple data points at the same speed, which is crucial for calculating the average force and the standard deviation of measurements. Microsoft Excel was employed for statistical calculations, data analysis, and graph generation.

Initially, the average drag force was calculated using simple arithmetic mean for each speed. Considering that the measured data are entirely experimental, utilizing prototyping electronics, it is expected that the data may contain noise. Therefore, for the purpose of calculating the average, the data were analyzed using a boxplot graph. This graph enables the visualization of position trends, symmetries, dispersion, and outliers (MORETTIN; BUSSAB, 2017). After evaluating the data, the arithmetic mean was calculated as follows in **Equation 12**:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (12)$$

As mentioned earlier, the function of the spill hole is to reduce the turbulence caused by the airflow circulating from the interior to the exterior of the canopy. By reducing this turbulence, the descent of the parachute becomes more stable. According to Fox, Pritchard, and McDonald (2014), turbulent flow "is one in which fluid particles rapidly mix as they move along the flow due to random fluctuations in the three-dimensional velocity field" (p.72). Thus, it is assumed that the significant variation in the velocity of particles comprising turbulent flow can lead to variations in drag force, as it directly depends on velocity.

Thus, from a statistical standpoint, support can be obtained from measures of dispersion, which summarize the variability of a sample of data, allowing the assessment of how the data deviate from the sample mean (MORETTIN; BUSSAB, 2017). The measure utilized in this context is the sample standard deviation, defined by:

$$S = \sqrt{\frac{(x_i - \bar{x})^2}{n-1}} \quad (13)$$

Therefore, a higher standard deviation indicates greater dispersion and variation of the data relative to the mean, suggesting greater instability in the system.

RESULTS

Using the collected data presented in the appendix tables, the average drag force, its standard deviation, and drag coefficient were calculated using the previously described equations. The theoretical drag force represents the result obtained using **Equation 1**. For display in the following table, four decimal places were considered, adhering to the rounding rules of ABNT/NBR 5891 (Brazilian Association of Technical Standards, 1977). The calculations were performed directly in Excel, yielding the following results (**Table 3)** for the parachute with a 5% spill hole:

Table 3- Results for 5% spill hole parachute (forces are in newtons)

Data X Speed	15 m/s	17 m/s	25 m/s
Theoretical drag force	15.5708	19.9998	43.2521
Measured drag force	11.7874	34.7002	52.9235
Standard deviation	2.1408	2.0371	5.0180
Drag coefficient	0.5905	1.3533	0.9544

Source: own authorship.

Following the same reasoning and methodology as the test with the previous model, the following results were obtained for 10% parachutes (**Table 4)**:

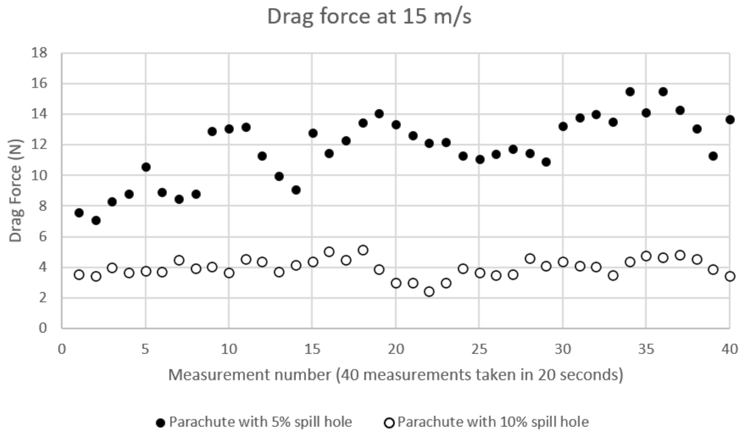
Table 4 - Results for 10% spill hole parachute (forces are in newtons)

Data X Speed	15 m/s	17 m/s	25 m/s
Theoretical drag force	15.4537	19.8494	42.9269
Measured drag force	3.9755	18.7795	39.8666
Standard deviation	0.5877	1.1457	1.2760
Drag coefficient	0.2007	0.7380	0.7244

Source: own authorship.

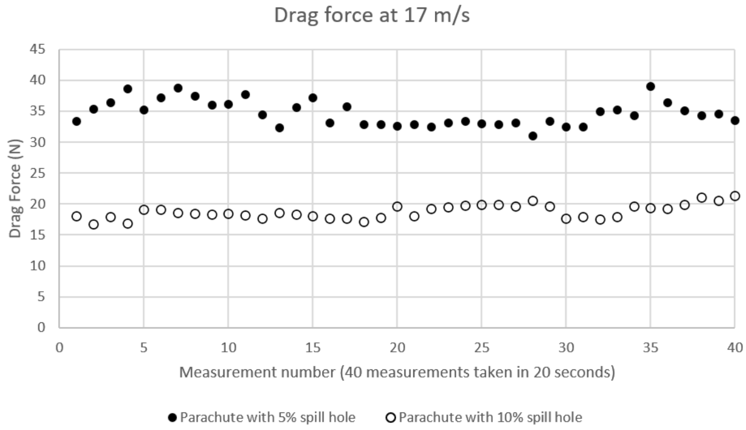
To better analyze the dispersion of drag forces at different speeds and compare the two spill hole diameters, scatter plots were used, representing the 40 measurements taken at each speed, continuously over 20 seconds. This means one measurement every 0.5 seconds. The graph provides an idea of trend and correlation, even if it is a rough one (CRESPO, 1996).

Figure 5 – Dispersion graph: comparing 5% and 10% spill hole parachutes at 15 m/s



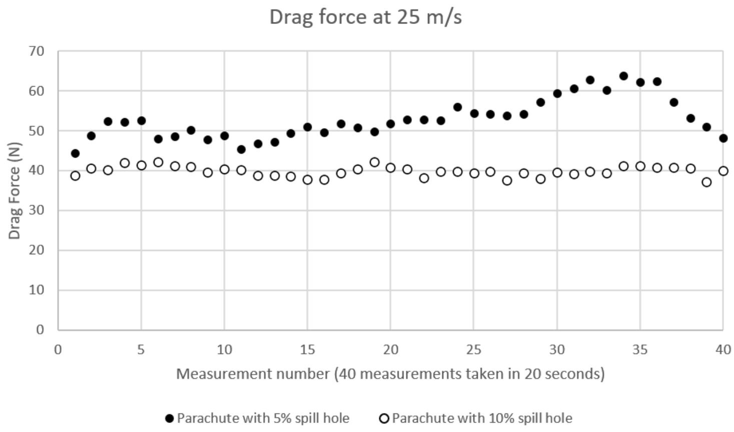
Source: own authorship.

Figure 6 – Dispersion graph: comparing 5% and 10% spill hole parachutes at 17 m/s



Source: own authorship.

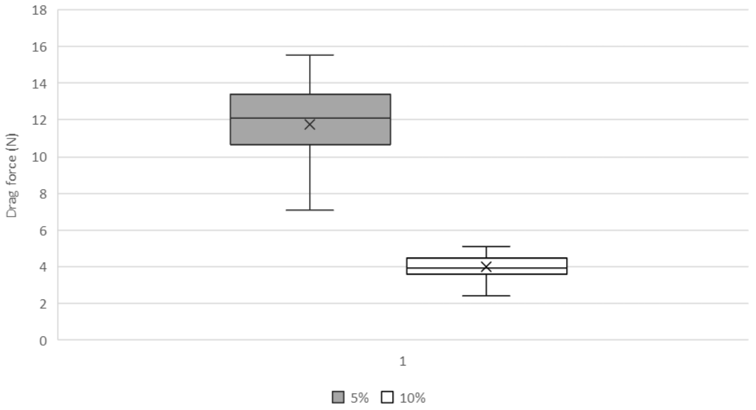
Figure 7 – Dispersion graph: comparing 5% and 10% spill hole parachutes at 25 m/s



Source: own authorship.

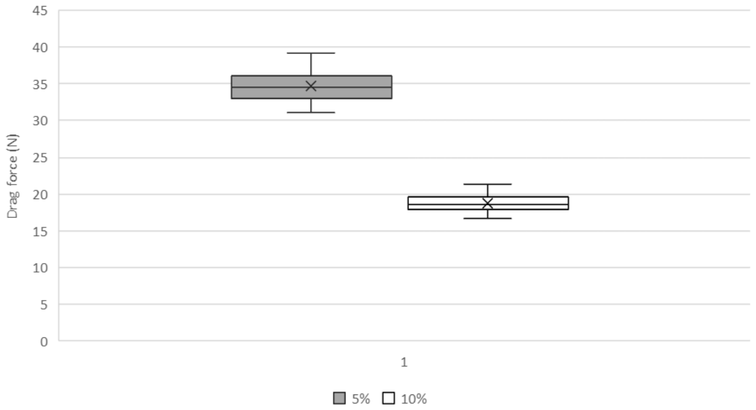
The boxplot graph was also used to check the data distribution and its range (upper and lower limits). This type of graph is employed to visualize outliers, identifying the range where the data is concentrated through quartiles (MONTGOMERY; RUNGER, 2003).

Figure 8 – Boxplot graph: 5% and 10% spill hole parachutes at 15 m/s



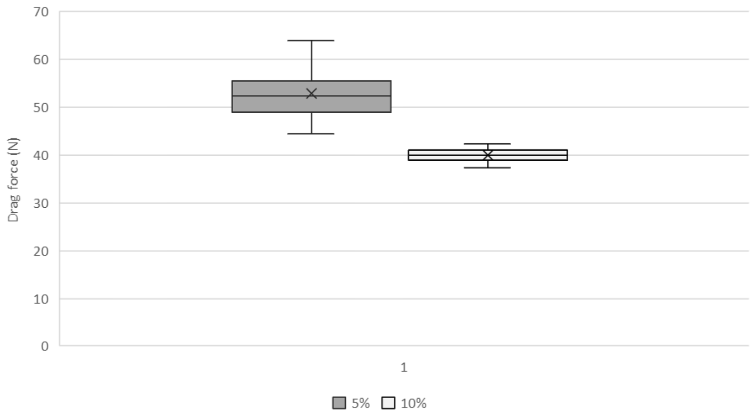
Source: own authorship.

Figure 9 – Boxplot graph: 5% and 10% spill hole parachutes at 17 m/s



Source: own authorship.

Figure 10 – Boxplot graph: 5% and 10% spill hole parachutes at 25 m/s



Source: own authorship.

Regarding error propagation, the main source is the load cell, responsible for generating the data used in the analysis. Information related to its accuracy is listed in the **Instrumentation** section.

CONCLUSION

Focusing on the results from **Tables 2 and 3**, a discrepancy in the data for the 15 m/s velocities is apparent, especially when observing the drag force and its coefficient compared to other velocities. Such discrepancy can be understood by considering that the parachute was not fully inflated at that point, resting against the tunnel surfaces, as observed in the test videos. This led to a reduction in the drag force.

Regarding the variation in the measured drag force, a higher standard deviation in the data was observed for the parachute with a 5% spill hole across all measurement speeds. Considering that a higher standard deviation indicates greater dispersion of measurements, this trend suggests increased instability, as there is more variation in the forces. For the 15 m/s velocity, the standard deviation of the 5% spill hole parachute drag force is 3.6427 times greater than that of the 10% parachute. For the 17 m/s velocity, the difference is 1.7780 times. As for the nominal 25 m/s velocity of this test, the standard deviation of the 5% parachute is 3.9326 times greater. Thus, the improvement in stability resulting from the increased diameter of the device becomes evident.

The dispersion graphs revealed a greater variation in the drag force of the 5% parachute at all velocities, suggesting increased instability in this system. The boxplot graphs show a wider range in the distribution of drag force values for the mentioned parachute, whereas the 10% parachute exhibits values concentrated within a smaller range.

FINAL REMARKS

The increase in the spill hole from 5% to 10% of the total parachute diameter results in a substantial improvement in its stability. The standard deviation of the drag force is 3.9326 times smaller in the 10% parachute compared to the 5%

parachute, ensuring a safer and more predictable descent of the rocket. The graphical analysis, using dispersion graphs and boxplots, shows that the measured drag force values at each velocity are less dispersed and more concentrated in the 10% parachute.

The results found are in line with what was suggested by Knacke (1992), who stated that parachutes with a spill hole, referred to by him as a canopy vent, with an area equal to 1% of the total parachute area, were successful in increasing their stability. It is important to highlight that 10% of the diameter of a circular projection is equivalent to 1% of its area.

In the field of computational fluid dynamics (CFD), Dawoodian, Dadvand, and Hassanzadeh (2013) also found a positive correlation between the presence of a spill hole and stability, varying the diameter ratio from 0% to 20%. In their research, they observed that a parachute with a 12% spill hole achieved better stability than one with 4%. However, the percentage increase of the spill hole also reduces its drag coefficient, in addition to the effective area of the parachute. Thus, a larger parachute would be necessary to provide the same drag. Due to this, the need to increase the parachute size should be carefully evaluated, as the rocket imposes weight and size constraints.

A significant amount of research on spill holes can be found for military parachutes. However, information related to the field of rocketry remains scarce. Virtual forums in the sector also suggest that a diameter ratio of 10 to 12% is ideal for spill holes in such applications. This research provides a more data-driven perspective on the subject, enabling an efficient choice of spill hole size.

A suggestion for future work is to use a wind tunnel with a larger test section, aiming to reduce the blockage ratio. While this could also be achieved by decreasing the parachute diameter, decreasing the object's diameter while keeping the fluid parameters unchanged requires an increase in flow velocity to maintain a constant Reynolds number, as can be observed from **Equation 2**. This is because maintaining Reynolds number similarity with actual flight is the primary goal of a wind tunnel test (ANDERSON, 1988).

Nevertheless, having a wind tunnel with a larger cross-sectional area in the test section will be a challenge, as experienced in this study. In Brazil, there are few wind tunnels available and, the larger the size of the tunnel, the higher the operational costs.

Given the failure that occurred with the load cell, it is important, in future works, to consider a backup load cell with the same specifications as the original one designated for the test. This precautionary measure can also be extended to other equipments.

Impacto do *spill hole* na estabilidade do paraquedas de um foguete experimental

RESUMO

O foguetemodelismo é uma prática que vem crescendo no Brasil, principalmente nas universidades. Um dos maiores desafios dessa atividade é o sistema de recuperação, responsável por garantir uma descida segura do foguete. Esse trabalho objetivou analisar a eficiência um paraquedas em escala, com o uso de túnel de vento, para confrontar os dados obtidos com os presentes na literatura. Verificou-se a influência do diâmetro do *spill hole*, utilizando um dispositivo com 5% e 10% de diâmetro em relação ao diâmetro total do paraquedas, na estabilidade durante a queda. Baseado nisto, os ensaios foram realizados usando modelos em escala em um túnel de vento da Universidade Federal de Minas Gerais, conservando as condições ambiente para os dois modelos. Os resultados dos ensaios mostraram que o paraquedas com *spill hole* maior tinha estabilidade significativamente melhor, com menor variação na força de arrasto. O paraquedas de 5% apresentou desvio padrão nos valores da força de arrasto 3,9 vezes maior que o paraquedas de 10% (a uma velocidade de escoamento de 25 m/s). Os resultados sugerem um aumento no coeficiente de arrasto do paraquedas com abertura no velame menor, resultando em maior força de arrasto.

PALAVRAS CHAVE: *Spill hole;* Estabilidade de paraquedas; Coeficiente de arrasto.

Impacto del *spill hole* en la estabilidad del paracaídas de un cohete experimental.

RESUMEN

El modelismo de cohetes es una práctica que ha ido creciendo en Brasil, especialmente en las universidades. Uno de los mayores desafíos de esta actividad es el sistema de recuperación, responsable de garantizar un descenso seguro del cohete. Este trabajo tuvo como objetivo analizar la eficiencia de un paracaídas a escala, utilizando un túnel de viento, para confrontar los datos obtenidos con los presentes en la literatura. Se examinó la influencia del diámetro del orificio de salida (*spill hole*), utilizando un dispositivo con un 5% y 10% de diámetro en relación con el diámetro total del paracaídas, en la estabilidad durante la caída. En base a esto, se realizaron experimentos utilizando modelos a escala en un túnel de viento de la Universidad Federal de Minas Gerais, manteniendo condiciones ambientales para ambos modelos. Los resultados de los ensayos mostraron que el paracaídas con un *spill hole* mayor tenía una estabilidad significativamente mejor, con una menor variación en la fuerza de arrastre. El paracaídas del 5% presentó una desviación estándar en los valores de la fuerza de arrastre 3.9 veces mayor que el paracaídas del 10% (a una velocidad de flujo de 25 m/s). Los resultados sugieren un aumento en el coeficiente de arrastre del paracaídas con una abertura de velamen más pequeña, lo que resulta en una mayor fuerza de arrastre.

PALABRAS CLAVE: *Spill hole*; Estabilidad de paracaídas; Coeficiente de arrastre.

ACKNOWLEDGMENTS

The authors would like to thank the Federal University of Minas Gerais, hereby represented by Professors Guilherme Papini and Cristiano Melo, for providing access to the wind tunnel. The authors also would like to thank the Aerospace Development Group from the Federal University of Ceará.

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Recebido: 17 de janeiro de 2024.
Aprovado: 24 de outubro de 2024.

DOI:

Como citar: MARTINS, A A; WEHMANN, C F, Impacts of the spill hole in the stability of a model rocket parachute, **Revista Brasileira de Física Tecnológica Aplicada**, Ponta Grossa, v. 11, n. 2, p. 1-17, dez. 2024.

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