Experimental Analysis of the Influences of Design Characteristics on Parachutes Performance

Rafael Guedes Lang, rglang@hotmail.com
Thiago Rocha de Araujo, thiago.rocha.araujo@usp.br
Manoel Antônio Delatre Bonfim Júnior, manoel.bonfim@usp.br
Marcos Vinícius Fernandes Ribeiro, ribeiro.mvf@gmail.com
Hernán Darío Cerón-Muñoz, hernan@sc.usp.br
Paulo Celso Greco Júnior, pgreco@sc.usp.br
Department of Aeronautical Engineering
São Carlos School of Engineering
University of São Paulo
400 Trabalhador São-carlense Ave.
São Carlos, SP – 13566-590
Brazil

Abstract. *This paper brings an experimental analysis of the influence of several characteristics on parachutes aerodynamic performance. Several mechanic and electronic tools are used to ensure properly operation of a rocket. These devices are usually expensive or difficult to build, therefore a reliable recovery system is an important part of the assembly. A common alternative is the use of parachutes, devices that reduce an object speed by generating drag, an aerodynamic force opposite to the movement sense. This force depends on many characteristics, such as the area, geometry and speed of the parachute. This article presents a full factorial experiment which analyses the influence of each of these factors on the system performance. Parachutes with three shapes, two areas and three stability systems were tested in a wind tunnel with speeds from 5 m/s to 30 m/s and the measured drag force was used as the response variable of the experiment. The analysis showed that the size and the speed of the parachute have great influence on its performance and that cross-shaped configurations generate more drag than the other ones. Therefore a recovery system design can be based on this shape, providing better aerodynamic performance, improved reliability and more safety to the structure and components of a rocket during its operation.*

Keywords*: Parachute, Rocket Recovery System, Full Factorial Experiment*

1. INTRODUCTION

A rocket is a machine that moves due to exhaustion of gases generated from combustion inside its motor (Hunter, 1966). It has been used since the 1200's and rapidly improved its altitude and speed ranges. At the beginning of the 20th century scientists began to see rockets as machines that could be used to give propulsion to other objects (Turner, 1997).

Even being very simple and small, the first rockets already had many of the characteristics of the ones that are used nowadays, such as multi-stages, liquid fuel and gyroscopes (Goddard, 1919). The technology evolution made possible the use of rockets to launch satellites, transport people and conduct on-the-fly microgravity and weather experiments, incorporating many refined mechanical and electronic devices in order to control and protect the operation of the rocket. These payloads and equipment require proper recovery as they can be expensive, unique, classified or even living beings.

A very effective recovery system is the use of parachutes, devices that decelerate the object speed by generating an aerodynamic force that opposes the movement (Rasmussen, 1985). They date back from the Renaissance and are still in constantly improvement (Baker, 1978). Although many shapes appeared during the years, elliptic, cruciform and rectangular ones are the most used, with some small variations. Besides the main parachute, the use of a smaller drag generator is frequent in order to stabilize the system and provide a smooth flight (Rasmussen, 1985).

An important question is the choice of the configuration that shall be used in a recovery system, as there are unnumbered possibilities and still some uncertainty about how to ponder each variable of the project.

2. EXPERIMENT DESIGN

In order to study the impact each characteristic has on the system performance and, thus, how much it is important during the design of the parachute, a full factorial experiment was conducted. This kind of experiment uses any interesting system outcome, from now on called response variable, to quantify the performance of a tested configuration of factors and their levels. Every single permutation is examined to find the effect of the factors and their interactions on the overall response (Jain, 1991).

This paper analyzed the influences of different parachute shapes, areas, stability systems and speeds on its performance and used the generated drag force as the design response variable. To perform the tests, six model parachutes were manufactured using a rip-stop nylon fabric and fixed to a load cell assembled in a wind tunnel, allowing effective control of the wind speed and measurement the produced drag.

The tunnel specifications guided the choice of the investigated areas and speeds as it can reach up to 35 m/s in a test section of 1.2 m x 1.7 m. The chosen shapes and stability systems were selected as the easiest to build of the most commonly used (Henke, 1974). A cross made from five equal squares, an ellipsoid of circular attack edge and elliptic section of $1/\sqrt{2}$ eccentricity and a ring of the same shape with a central hole of 25% of the area were the selected shapes. Small cross drogue parachutes with ¼ of the model's area and twelve leather ribbons of 5 x 50 cm, called streamers, were used as stability systems. Table 1 presents and labels the chosen factors and levels. Figure 1 shows one of the tested elliptic models.

Factor	Levels
Shape	Cross (C), Ring (R), Ellipsis (E)
Area	0.3125 m^2 (S), 0.625 m^2 (B)
Stability system	None (N), Drogue parachute (D), Drag streamers (S)
Speed	From 5 m/s to 30 m/s by 5 m/s

Table 1: Factors and levels of the experiment with their corresponding labels.

Figure 1: Small elliptic model parachute used in experiment.

The acquisition system consisted of a load cell, that was calibrated with standard weights to measure forces up to 150 N, connected via a LabView software to a HBM MGCplus signal amplifier that took 500 measurements within two seconds for each test after the stabilization of the wind speed.

The tunnel speed is defined by the frequency of its motor and the wind speed cannot be directly set. The experiments were conducted according to this frequency, from 10 to 35 Hz by 5 Hz, and a micromanometer with a *Pitot* tube were used to obtain the speeds. The measured speeds and drags were applied by the software Minitab in a second degree polynomial regression to obtain the Drag x Velocity curves. The tests responses for each speed level were obtained from these curves and used at the factorial analysis of the experiment, also done with Minitab.

3. RESULTS AND DISCUSSION

The described procedure provided precise Drag x Speed functions as showed in Tab. 2 and Fig. 2 for the ring small parachute with drogue chute (RSD) experiment. Table 2 presents the statistical data obtained from the measurements and Fig. 2 shows the Drag x Velocity curve resultant of the polynomial regression.

Motor Freq (Hz)	Wind Speed (m/s)	Avg Drag (N)	Std Deviation (N)	95% CI (N)	90% CI (N)	Minimum (N)	Maximum (N)
10	6.14	1.79	0.15	± 0.01	± 0.02	1.54	2.10
15	9.70	4.24	0.36	± 0.03	± 0.04	3.46	4.92
20	13.20	8.12	0.62	± 0.05	± 0.07	6.96	9.51
25	16.79	12.40	1.39	± 0.12	± 0.16	9.38	15.44
30	20.38	17.26	1.22	± 0.11	± 0.14	14.76	20.40
35	23.99	24.65	1.89	± 0.17	± 0.22	20.20	29.56

Table 2: Statistical data of the RSD test.

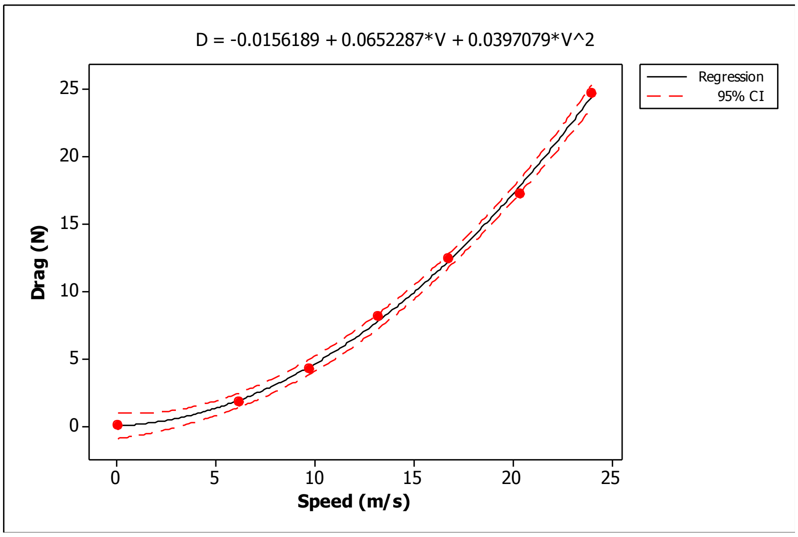

Figure 2: RSD test non-linear regression plot with confidence interval.

In order to obtain the drag generated at the desired speeds, the procedure was repeated for every factor/level configuration and Figs. 3 and 4 show the fitted curves for all of them. The plots have similar traces, rapidly increasing with speed and two main clusters corresponding to the drag of different sizes parachutes.

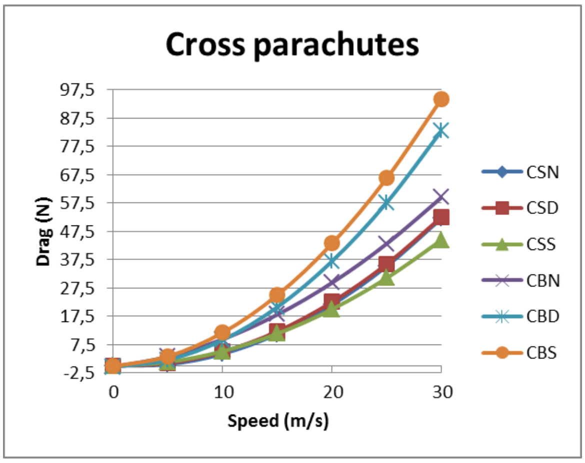

Figure 3: Regression plots for cross parachute configurations.

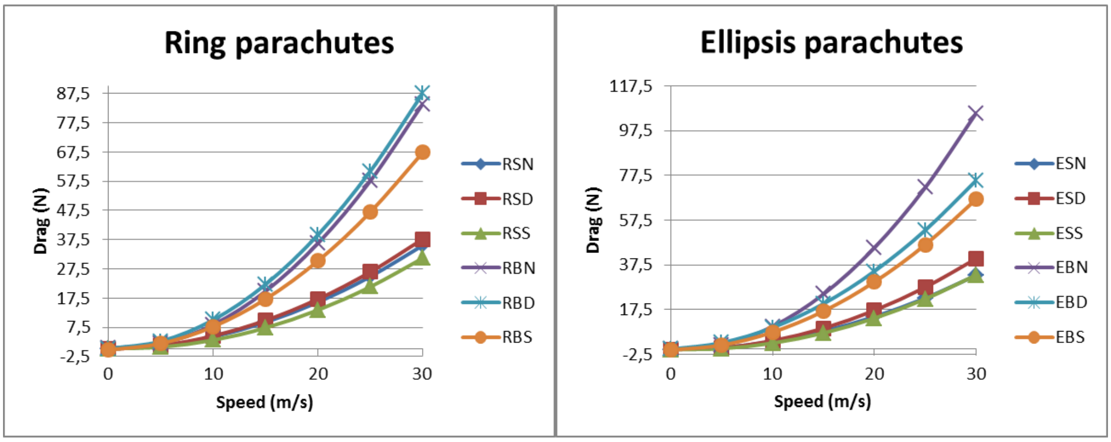

Figure 4: Regression plots for ring and ellipsis parachute configurations.

The factorial analysis takes the responses of all analyzed variables (speed, stability system, speed and shape) and calculates its average value, determining how much it impacts on the overall response (Jain, 1991).

Figures 5 and 6 show the main effects of each factor. Size and speed revealed direct influences, increasing the generated drag as they grow. In contrast, different stability systems or shapes showed no effects on the final response. However, the improvement of the cross-shaped model compared to the others, even if not statistically significant, was 13.4% to the ring and 11.3% to the ellipsis, values that could not be ignored and requested a study of the influence of factors interactions.

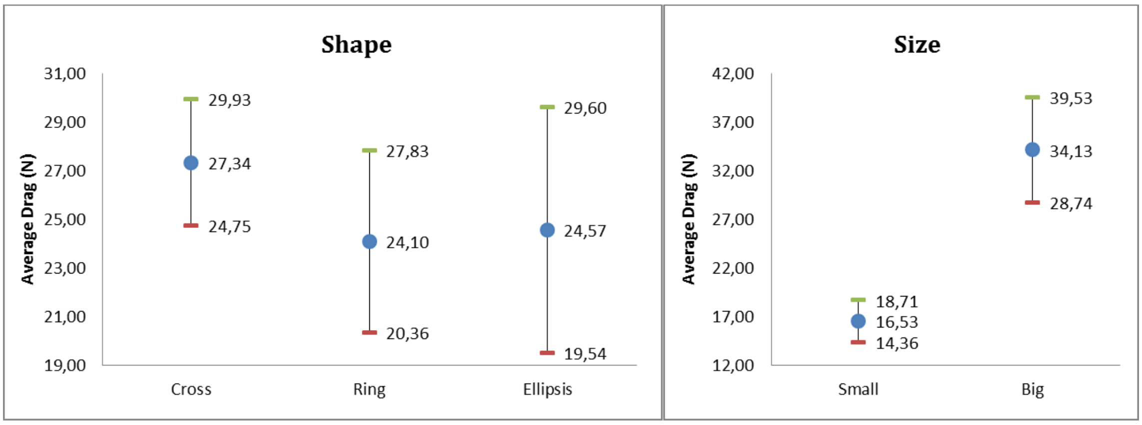

Figure 5: Parachute shape and size influences.

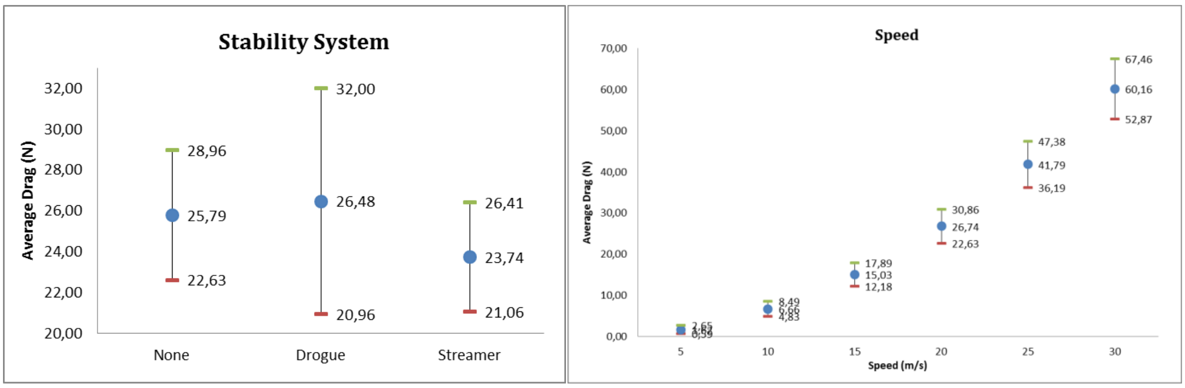

Figure 6: Parachute stability system and speed influences.

In a deeper analysis, Fig. 7 demonstrates that the shape did not affect big parachutes performance, as each average fitted in all other confidence intervals. However, on the small ones, the cruciform model showed significantly more drag than the others, attesting performance superiority.

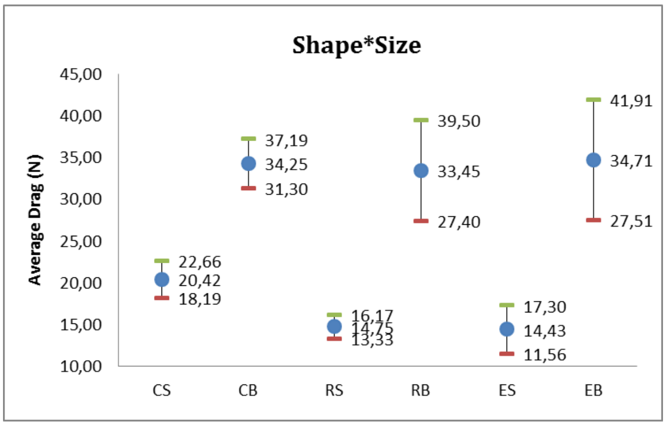

Figure 7: Interaction of shape and size influences.

The error of the measurement apparatus and an inappropriate choice of the models' size were crucial aspects on the analysis of the cross parachute. Turbulence generated by the tripod with the load cell created an unstable test, increasing the standard deviations. Similarly, the big parachutes' sizes allowed them to hit against the walls of the tunnel, preventing a more precise measurement. Considering, based on the errors presented in Figs. 5 and 7, that the small parachutes were more stable, as they could not hit the walls, and that the difference from the big cross to the others big parachutes is significant, it can be assumed that the cross parachute has a better performance than the other shapes and that a more accurate experiment would be able to prove it.

4. CONCLUSIONS

Despite of the results that could be obtained from a more precise experiment, this work statistically showed that the main influences on a parachute performance are its size and speed, and that different shapes or stability system shall not change the generated drag. Further, it has also proposed, considering the great but not statistical superiority, that the cruciform parachute, besides being easy to manufacture, can be more efficient than the other shapes, although it could not be generally proved with our measurement apparatus and should be studied in future more accurate works. The influences presented by these factors can be the base for the development of simple and reliable recovery systems that shall allow safer use of expensive, fragile or even living payloads on rockets.

5. ACKNOWLEDGEMENTS

The authors would like to thank Prof. Dr. Fernando Catalano, José Cláudio de Azevedo, Fábio Gallo and the technicians of the Machines and Tools Laboratory (LAMAFE) for the help with the wind tunnel experiments, Dawson Izola for the load cell used in this work, Maiara Rosa and the Advanced Robotics Study Group of the Dept. of Electrical Engineering for the help with the models manufacture and the colleagues of the TOPUS Aerospace Researches Group for the support and company during the project.

6. REFERENCES

Baker, D., 1978, "The rocket: the history and development of rocket & missile technology", Ed. Crown, London, 276 p.

Goddard, R. H., 1919, "A Method of Reaching Extreme Altitudes (with 10 plates)", Smithsonian Miscellaneous Collections, Vol. 71, No. 2, USA, pp. 1-69, plus 10 pages of plates

Henke, D., 1974, "Scale drogue parachute models", Goodyear Aerospace Co., USA, 48 p.

Hunter II, M. W., 1966, "Thrust into space I", Ed. Holt Library of Science, USA, 224 p.

Jain, R., 1991, "Art of computer systems performance", Wiley Computer Publishing, USA, 685 p.

Rasmussen, A. M., 1985, "Solid rocket booster retrieval operations", NASA Conference Publication, n pt. 1, USA, pp. 505- 509

Raymer, D. P., 2006, "Aircraft design: A conceptual approach", AIAA Education Series, USA, 745 p.

Turner, M. J. L., 2008, "Rocket and spacecraft propulsion", Ed. Springer - Praxis, Germany, 390 p.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.