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DESIGNING AND TESTING AN AERODYNAMICALLY STABILIZED ROCKET FOR STUDENT COMPETITION

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Abstract. *In order to win the 8th edition of the Intercollegiate Rocket Engineering Competition, the ITA Rocket Design team, represented by its Aerodynamic group, must design and build an aerodynamically stable rocket. Some important aerodynamic changes from the last year project were proposed in order to achieve a Static Margin between 1 and 2 calibers. This work shows the calculations and all the considerations to prove that these changes indeed make the rocket statically stable and can guarantee a high flight score by achieving as near of 10.000 feet altitude (about 3 km) as possible by reducing the rocket total drag. Finally, the results of the test flight, with the rocket engineering mode,l and of the competition flight, with the full power rocket, are discussed to understand the exact influences of the aerodynamic design and predictions.*

Keywords: *ITA Rocket Design, IREC, Rocket Aerodynamic, Rocket Stability*

1. INTRODUCTION

Every year the Experimental Sounding Rocket Association – ESRA, a non-governmental agency who supports universities all over the world to exchange and improve their rocket science and engineering knowledge, foments the Intercollegiate Rocket Engineering Competition – IREC. The competition is held on the city of Green River, Utah, USA at the end of June. On its 8th edition, more than 20 teams must build rockets able to fulfill three well defined requirements: carry a 10 pounds payload, reach exactly 10.000 feet altitude and be reflyable.

The Instituto Tecnológico de Aeronáutica – ITA, one of the few brazilians engineering schools with aerospace engineering graduation, participates at the IREC since its 6th edition with its ITA Rocket Design team. Even with less than three years of existence, the team had conquered several prizes at the competition, including the third overall score and the best project score of its class on both years.

This year, there were some major changes on the competition rules, emphasizing the rocket aerodynamic stability. Quoting: "Rockets shall be statically stable (but not overstable) for the entire ascent (regardless of Center of Gravity – CG position, movement of Center of Pressure – CP due transonic effects, etc.). Static margin should be between 1 and 2 calibers".

This work will show the calculations used, some tools developed and all the procedures taken by the team's aerodynamic group to prove the rocket meets those requirements. Finally, the concept is put to test in two different occasions: the maiden flight in Brazil with the rocket engineering model and the competition launch in the United States with the complete rocket.

2. ROCKET CONFIGURATION CHANGE

The 7th IREC was held between June 22 and 26, 2012, during the hot and windy summer at the desert near the city of Green River, Utah. At the launch of ITA Rocket Design team's overstable rocket, the strong winds changed the path of the rocket so it could not be found after touchdown. During the team's debriefing, a critical analysis was done to find why the rocket configuration was overstable, how it influenced the flight and which measures could be taken to avoid this problem.

Figure 1 shows the exploded view of this 3 inches in diameter and 2.3 meters tall rocket. It can be divided into 3 main parts: at the bottom, the rocket motor; at the middle, the payloads and parachutes; and at the top, the Cansat. A more detailed explanation of the rocket system can be found at the last year report.

As the rocket burns its propellant, the Center of Gravity – CG tends to go up, from somewhere near the middle of the rocket motor to somewhere near the Bulkhead, where the 10 pounds payload is located. On the other hand, as the rocket accelerates, the Center of Pressure – CP tends to go down near the aerodynamic surfaces, the fins. These movements raise the Static Margin – SM and can make the rocket overstable.

During the system development, one of the first baselines was the use of 3 inches tubes, easily found at the markets, to build the entire rocket body. When calculating the rocket motor, it had to be very long to hold its almost 3 kg AP/HTPB solid grain. Knowing that the fins must be built at the end of the rocket and with last paragraph considerations, the rocket was, by design, overstable. Making the calculations, it can be found that the 7th IREC rocket had a SM between 4 and 4.5 calibers.

But the fact of being overstable would not be a problem if the rocket leaves the launch rail with high velocities compared with the transverse winds. In other words, there is no problem with an overstable flight if the angle of attack α is always near zero. This condition is easily achieved manipulating the thrust curve of the motor by casting, for example, a star shaped grain, as contemplated by the project and showed in Fig. 1.

However, other factors besides the plain calculations must be taken into account when designing a competition rocket. There were several differences between the propellants found in Brazil compared to the ones acquired in the USA. For example, the propellants granulation in Brazil was much higher, the propellants impurity in the USA was higher and the plastificant found in the USA didn't work so well. These differences made almost impossible to cast the star shaped grain without breaking it while taking off the mandrill. As a last minute project change, it was used a cylindrical mandrill, which is easier to take off. The resulted cylindrical grain has a lower thrust at the beginning of its burn, so the rocket had a lower acceleration and took off the launch rail much slower than expected. Summing it up with the high winds found at the region at the early afternoon, the rocket had a huge α input right after leaving the launch rail and, because of the *weathercock effect*, it aligned to the wind and was lost into the desert.

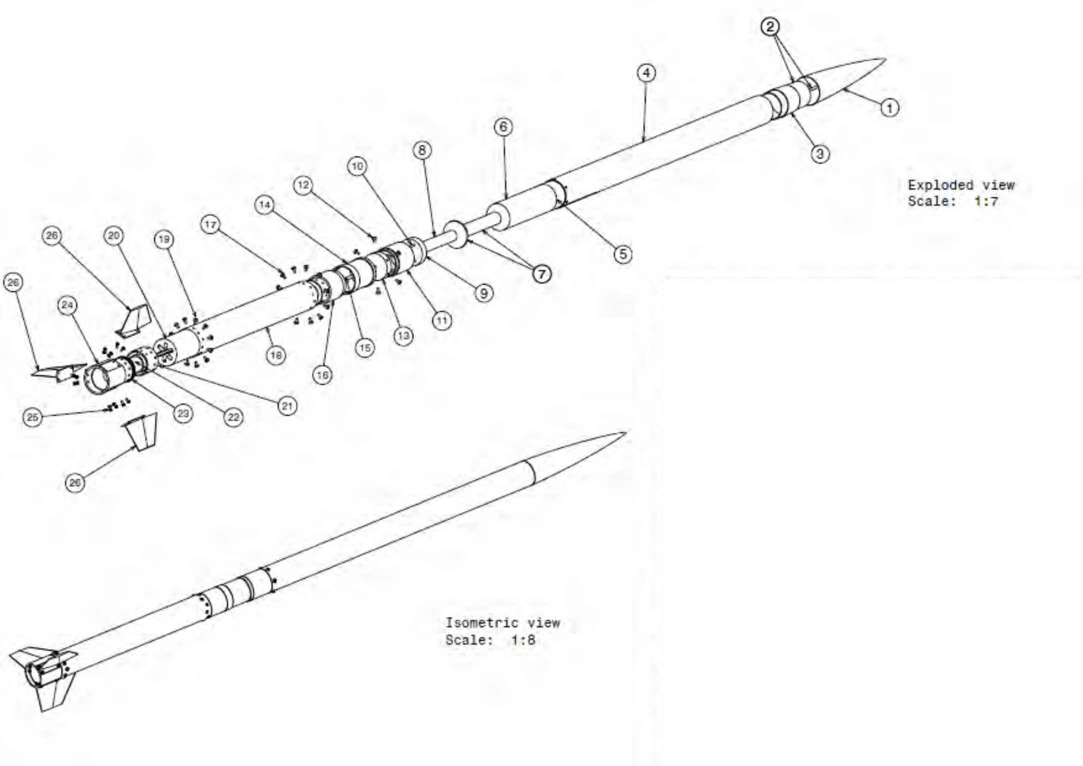

Figure 1. ITA Rocked Design team's rocket for the 7th IREC

According to what was explained and because of the SM competition requirement, the new project must have a smaller rocket motor, bringing the CG (near the bulkhead) closer to the CP (near the fins). To achieve this requirement, a new concept of rocket was proposed. Figure 2 shows the wider rocket motor, now with 4 inches. This change helps the propulsion feature of the motor, allowing it to carry the same or even more propellant with a smaller fineness ratio (defined by the ratio between the length and the diameter of the grain), which reduces erosive burn. On the other hand, a wider rocket motor case is structurally weaker, allowing a lower chamber pressure or demanding a thicker and heavier tube. During the Preliminary Design Review, this concept was approved by the systems engineering group as a viable option of a stable and powerful rocket design.

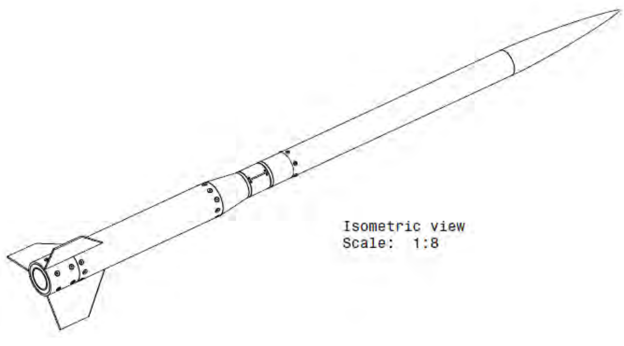

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Figure 2. ITA Rocked Design team's rocket for the 8th IREC

3. NOSE FAIRING

Before considering the stability effects of the aerodynamic surfaces, the nose fairing must be determined so the stabilization can be easily analyzed by only changing the fin surfaces. This section study is the same of the one made during the 7th IREC project, that focused on the drag coefficient reduction by changing the nose fairing profile.

According to Crowell, 1996, an optimized nose fairing for a transonic missile shall have no bluntness and bluffness because of its small influence below supersonic regime. The selection of the nose shape is done by comparing the results found on Figure 3.

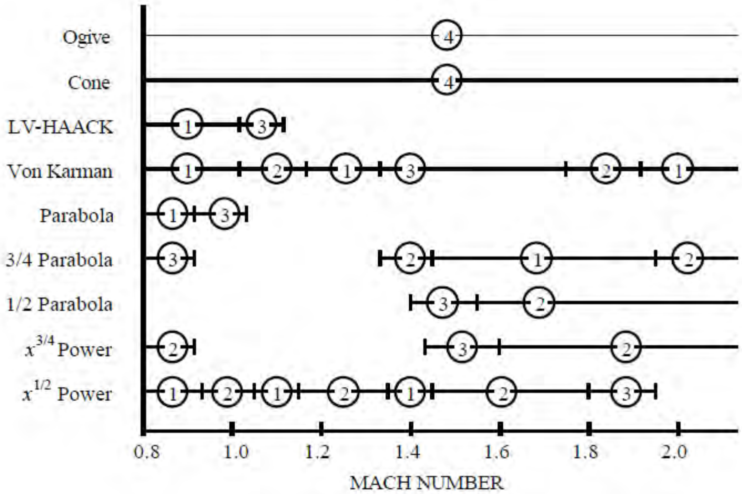

Figure 3. Comparison of drag characteristics of various nose shapes in the transonic-to-low Mach regions. Rankings are: Superior (1), Good (2), Fair (3), Inferior (4) (Crowell, 1996)

It clearly shows that for nearsonic rockets the LV-Haack and the Von Karman shapes have a higher efficiency compared with the common Ogival and Conical shapes. Because of the long term project done by the ITA Rocket Design team, it is possible that future rockets will trespass the sonic barrier. This makes today's choice of nose shape very important, especially because of the difficult process to build complex geometries like the nose fairing. The shape selected is the Von Karman, with a fineness ratio (ratio between nose length to its diameter) of 5. According to Figure 4, this ratio provides a significant reduction on wave drag for supersonic regimes. On the other hand, for subsonic flights, where this kind of drag is negligible, a big fineness ratio increases the friction drag. To surpass this problem, the rocket system tries to optimize the spatial usage inside the fiberglass nose fairing putting the Cansat inside it. It results in the reduction of the total length of the payload part and, in consequence, of the payload friction drag. Because its RF transparency characteristic, the nose fairing ended up to be the perfect place to this electronic device.

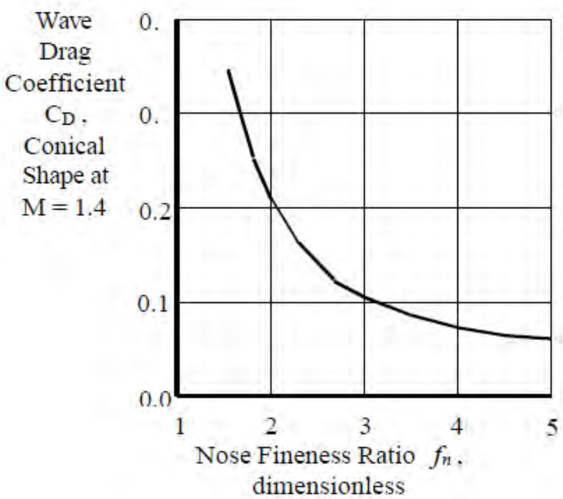

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Figure 4. Influence of the fineness ratio decreasing the wave drag coefficient for a conical shape nose fairing at M = 1.4 (Crowell, 1996)

The rocket nose fairing profile is easily found using the Von Karman shape equation, Eq.1. Considering that the payload cylinder diameter has 3 inches (76.2 mm) and the fineness ratio is 5, the values of R = 38.1 mm, L = 381 mm and $\theta(x)$ is described at the Eq. 2.

$$y = \frac{R\sqrt{\theta - \frac{\sin(2\theta)}{2}}}{\sqrt{\pi}} \quad (1)$$

$$\theta = \cos^{-1}\left(1 - \frac{2x}{L}\right) \quad (2)$$

After taking 100 points of that curve, as presented at the Figure 5, the nose fairing profile can be transferred to a CAD software where it can be splined and transformed into a 3D geometry. The Cansat part as designed with CATIA is shown at the Figure 6. Finally, the Figure 7 shows a photo of the real fiberglass nose fairing ready to be integrated with the Cansat electronics.

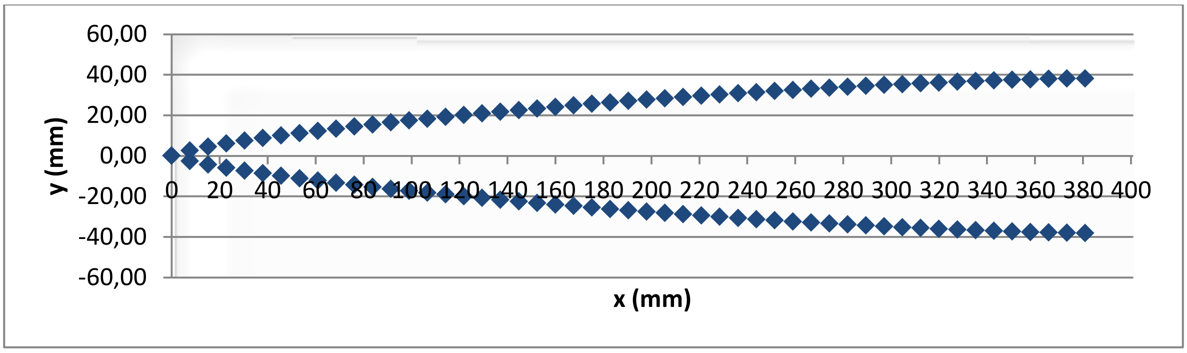

Figure 5. 100 points of the nose fairing profile using Von Karman shape equation Eq. 1

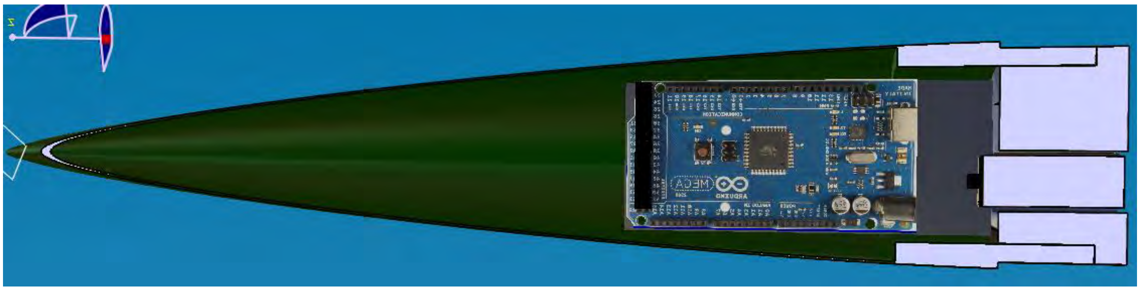

Figure 6. CAD drawing of the Von Karman nose fairing. The Cansat electronic is located inside the fairing because of the RF transparency characteristic of the fiberglass and to reduce the space needed of the payload part.

Figure 7. Fiberglass nose fairing based on Von Karman shape equation

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4. WIND ANALYSIS

To avoid the stability problems found during the 7th IREC, it was made an analysis of the wind on the launch region on a period of 7 days before the competition. It was taken the mean value of the hourly data of wind speed, max wind gust and the counting of their occurrences, resulting in a "mean day" profile.

Figure 8 shows the result of the wind speed profile. It can be seen that it doesn't vary so much throughout the day, maintaining always below 5 m/s. On the other hand, Figure 9 shows that the wind gusts intensities can reach above 9 m/s at the early afternoon and, according to Figure 10, this is the period when wind gusts count has a maximum during the day.

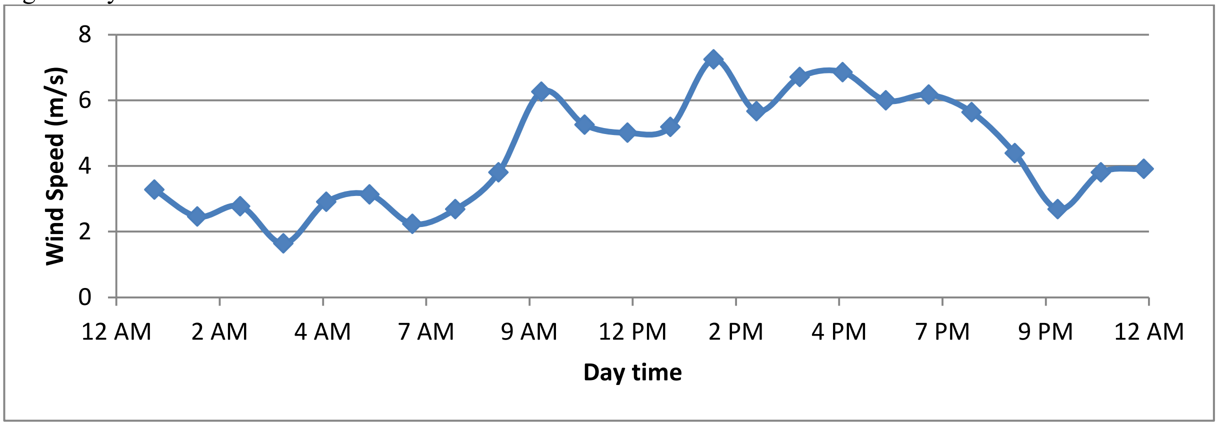

Figure 8. Wind speed profile for the mean day in the launch region

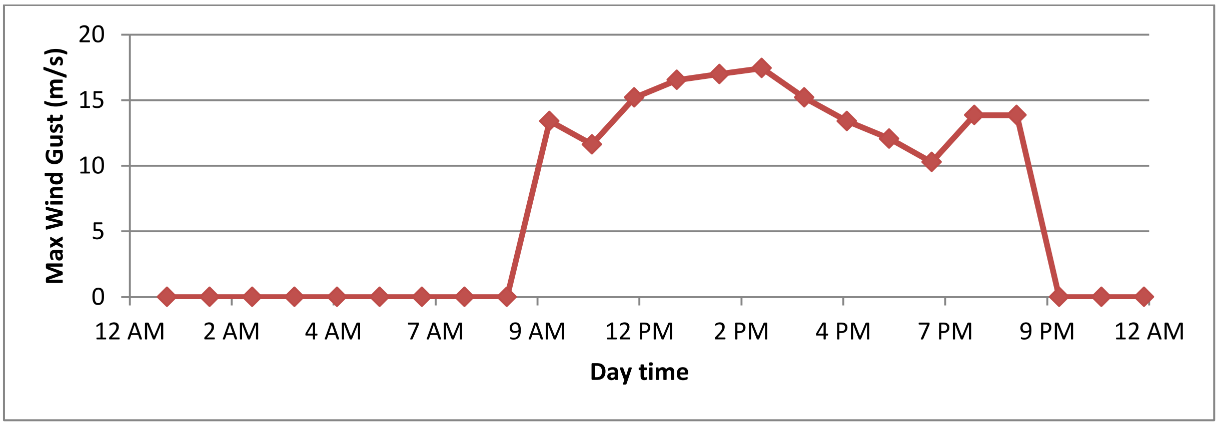

Figure 9. Max wind gust profile for the mean day in the launch region

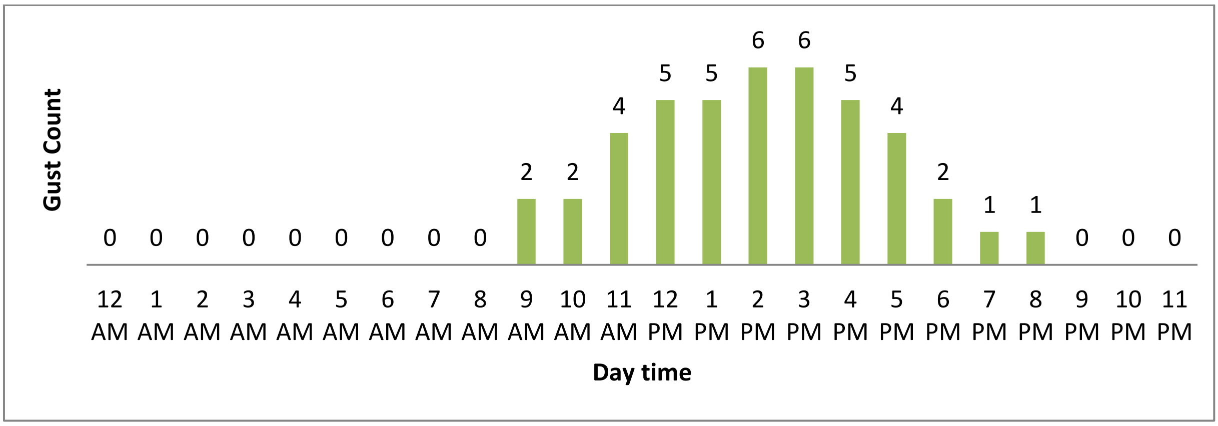

Figure 10. Wind gust count profile for the mean day in the launch region

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With these results it is clear that the best time to launch the rocket is at the morning. For elucidation, the 7th IREC launch happened around 3 pm, the worst scenario.

For designing purpose, it will be defined as aerodynamic requirement a maximum transversal wind speed of 9 m/s. On this extreme case, the maximum angle of attack α for each Mach number of the rocket flight is calculated using Eq. 3, where a is the speed of sound and M is the Mach number. The maximum theoretical speed of the rocket (and in consequence the maximum Mach number) can be calculated using Tsiolkovky equation, Eq. 4, where g_0 is the gravitational acceleration, Isp is the specific impulse (a propellant characteristic), M_0 and M_f are the initial and final rocket mass. The result shows a maximum Mach number of 0.85 and, then the maximum α for each Mach number can be found at the Tab. 1.

$$\alpha = \tan^{-1}(M.a/9) \tag{3}$$

$$\Delta v = g_0 Isp \ln(M_0 / M_f) \tag{4}$$

Table 1. Maximum angle of attack predicted to all flight conditions based on a transversal wind speed of 9 m/s

Mach	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
α (°)	14.8	7.5	5.0	3.8	3.0	2.5	2.2	1.9	1.7

5. CG MOVEMENT

Before designing the finset, it is recommended the most precise prediction of CG as possible. A well accurate prediction can be made using a CAD software during the rocket development. The correct densities of the materials can be found knowing the mass of former year's products. With those, it is easy to obtain all inertial properties of the rocket, including total mass, center of gravity and principal moments.

The 8th IREC design has the ability to slightly control the CG position by redistributing up to 1.5 kg of its payload mass (33% of total) from the main position (inside the Bulkhead) to the secondary position (inside the nozzle fairing). This flexibility allows eventual corrections due to differences between designed and real values of the rocket mass.

Table 2 shows the CG values of the full (before ignition) and empty (after burning) rocket for both extreme cases - with no nozzle payload and with maximum nozzle payload - all calculated using a CATIA model of the entire rocket.

Table 2. Rocket Center of Gravity positions before and after motor burning for two payloads configurations

$\mathbf{0\%\ nozzle\ payload}$	$\mathbf{100\%\ nozzle\ payload}$
$\boldsymbol{CG_{full} = 1491.7\ mm\ from\ tip}$ $\boldsymbol{CG_{empty} = 1455.4\ mm\ from\ tip}$	$\boldsymbol{CG_{full} = 1546.6\ mm\ from\ tip}$ $\boldsymbol{CG_{empty} = 1521.5\ mm\ from\ tip}$

For designing purpose, a mean value of CG is taken, as shown at Tab. 3.

Table 3. Rocket mean Center of Gravity positions to be considered during design phase

$\boldsymbol{Design}$
$\boldsymbol{CG_{full} = 1519.2\ mm\ from\ tip}$ $\boldsymbol{CG_{empty} = 1488.4\ mm\ from\ tip}$

6. FINSET DESIGN

Knowing the rocket CG position from section 5, the finset has to be designed so it can guarantee that the SM is between 1 and 2 calibers for all flight conditions defined at section 4. For the SM prediction it is used the public software Missile Datcom, '97, developed by the USAF (Blake, 1997). However, this computer program uses the not so friendly FORTRAN language, without any Graphic User Interface. Predicting the high usage of this program for flight condition simulation, the ITA Rocket Design Aerodynamic group developed an interface using Matlab environment, the DatcomIO, where the user can input the flight conditions (α and Mach) and the routine runs the Missile Datcom for the designated geometry and retrieves all aerodynamic coefficients, including the SM, into a Matlab matrix. Knowing the ITA Rocket Design Flight Dynamic group also uses a Matlab routine for flight path prediction, the common use of this language was highly recommended.

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Table 4. Rocket Static Margin values (in calibers) for several flight conditions. Each box is related to a defined Center of Gravity position. The negative values indicate the Center of Pressure is behind de Center of Gravity, making the rocket stable. The green cells enhance the Static Margin value between the limits of 1 and 2 calibers

CG=1540		Mach								
		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Alpha	0	-1,335	-1,341	-1,351	-1,366	-1,383	-1,401	-1,416	-1,444	-1,475
	2	-1,27	-1,274	-1,281	-1,294	-1,307	-1,323	-1,325	-1,341	-1,364
	4	-1,215	-1,217	-1,222	-1,232	-1,243	-1,256	-1,246	-1,25	-1,267
	6	-1,153	-1,153	-1,155	-1,162	-1,17	-1,181	-1,16	-1,152	-1,163
	8	-1,079	-1,076	-1,075	-1,079	-1,083	-1,091	-1,058	-1,04	-1,044
	10	-1,013	-1,006	-1,003	-1,003	-1,005	-1,01	-0,967	-0,938	-0,935
	12	-0,94	-0,931	-0,924	-0,918	-0,914	-0,914	-0,861	-0,822	-0,813
	14	-0,86	-0,846	-0,835	-0,824	-0,814	-0,806	-0,745	-0,699	-0,671
	16	-0,768	-0,75	-0,733	-0,718	-0,702	-0,685	-0,617	-0,548	-0,508

CG=1520		Mach								
		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Alpha	0	-1,532	-1,537	-1,547	-1,563	-1,579	-1,598	-1,613	-1,641	-1,671
	2	-1,467	-1,471	-1,478	-1,491	-1,504	-1,52	-1,522	-1,537	-1,561
	4	-1,412	-1,413	-1,419	-1,429	-1,44	-1,453	-1,443	-1,447	-1,464
	6	-1,35	-1,349	-1,352	-1,359	-1,367	-1,378	-1,357	-1,349	-1,36
	8	-1,276	-1,273	-1,272	-1,275	-1,28	-1,288	-1,255	-1,237	-1,24
	10	-1,209	-1,203	-1,2	-1,2	-1,202	-1,207	-1,164	-1,135	-1,132
	12	-1,137	-1,128	-1,121	-1,115	-1,111	-1,111	-1,058	-1,019	-1,01
	14	-1,057	-1,043	-1,032	-1,021	-1,011	-1,003	-0,942	-0,896	-0,868
	16	-0,965	-0,947	-0,93	-0,915	-0,899	-0,882	-0,814	-0,745	-0,705

CG=1500		Mach								
		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Alpha	0	-1,729	-1,734	-1,744	-1,76	-1,776	-1,795	-1,81	-1,837	-1,868
	2	-1,664	-1,667	-1,675	-1,688	-1,701	-1,717	-1,719	-1,734	-1,758
	4	-1,609	-1,61	-1,616	-1,626	-1,637	-1,65	-1,64	-1,644	-1,661
	6	-1,547	-1,546	-1,549	-1,556	-1,564	-1,575	-1,553	-1,546	-1,556
	8	-1,473	-1,469	-1,469	-1,472	-1,477	-1,485	-1,452	-1,434	-1,437
	10	-1,406	-1,4	-1,397	-1,397	-1,399	-1,404	-1,361	-1,332	-1,329
	12	-1,334	-1,325	-1,318	-1,312	-1,308	-1,308	-1,255	-1,216	-1,207
	14	-1,254	-1,24	-1,229	-1,218	-1,208	-1,2	-1,139	-1,092	-1,064
	16	-1,162	-1,143	-1,127	-1,111	-1,096	-1,079	-1,011	-0,942	-0,902

CG=1480		Mach								
		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Alpha	0	-1,926	-1,931	-1,941	-1,957	-1,973	-1,992	-2,007	-2,034	-2,065
	2	-1,861	-1,864	-1,872	-1,884	-1,898	-1,914	-1,916	-1,931	-1,955
	4	-1,805	-1,807	-1,813	-1,822	-1,833	-1,847	-1,837	-1,84	-1,858
	6	-1,744	-1,743	-1,746	-1,753	-1,761	-1,772	-1,75	-1,743	-1,753
	8	-1,669	-1,666	-1,666	-1,669	-1,674	-1,682	-1,649	-1,631	-1,634
	10	-1,603	-1,597	-1,594	-1,594	-1,596	-1,601	-1,558	-1,529	-1,526
	12	-1,531	-1,521	-1,515	-1,509	-1,504	-1,505	-1,452	-1,413	-1,403
	14	-1,45	-1,437	-1,425	-1,415	-1,405	-1,397	-1,336	-1,289	-1,261
	16	-1,359	-1,34	-1,324	-1,308	-1,292	-1,276	-1,208	-1,138	-1,099

CG=1460		Mach								
		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Alpha	0	-2,123	-2,129	-2,139	-2,154	-2,171	-2,189	-2,204	-2,231	-2,262
	2	-2,058	-2,061	-2,069	-2,081	-2,095	-2,111	-2,113	-2,128	-2,152
	4	-2,002	-2,004	-2,009	-2,019	-2,03	-2,044	-2,034	-2,037	-2,054
	6	-1,94	-1,94	-1,943	-1,95	-1,958	-1,969	-1,947	-1,94	-1,95
	8	-1,866	-1,863	-1,863	-1,866	-1,871	-1,878	-1,846	-1,827	-1,831
	10	-1,8	-1,794	-1,79	-1,791	-1,793	-1,798	-1,755	-1,726	-1,723
	12	-1,728	-1,718	-1,711	-1,706	-1,701	-1,702	-1,648	-1,61	-1,6
	14	-1,647	-1,634	-1,622	-1,612	-1,602	-1,594	-1,532	-1,486	-1,458
	16	-1,556	-1,537	-1,52	-1,505	-1,489	-1,472	-1,405	-1,335	-1,296

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It was chosen to use 3 fins to reduce drag and rocket complexity since the fins are one of the most difficult parts to be manufactured due to its unique shape. The fin geometry is based on the ones commonly used on Brazilian sounding rockets, a rectangle trapeze with a diamond profile. Some different kinds of planform were tested, looking for a finset that could keep the rocket stable for a large CG change. The final planform have the following proportions: 2L on the lower base, L on the height and L on the higher base. Finally, the total area is measured so the final allowable CG region contains the predicted CG position.

Table 4 shows the SM for the rocket with a CG placed from 1540.0 mm to 1460.0 mm from the tip for every condition of flight from Mach 0.1 to 0.9 and $\alpha = 0°$ to 16°. The bold cells show the maximum α for that Mach, agreeing with Tab. 1. Other consideration is that the first CG positions, with higher values, correspond the beginning of the flight, when the grain had not be burnt yet, where the last ones correspond to the ballistic flight, after propulsive phase.

It can be seen that the rocket is stable if its CG is placed between 1520.0 mm and 1480.0 mm, and can be tolerated for a CG between 1540.0 mm to 1460.0 mm. Comparing with the predicted CG position showed at Table 3, it is illustrated on Figure 11 that this rocket configuration is indeed, by design, statically stable.

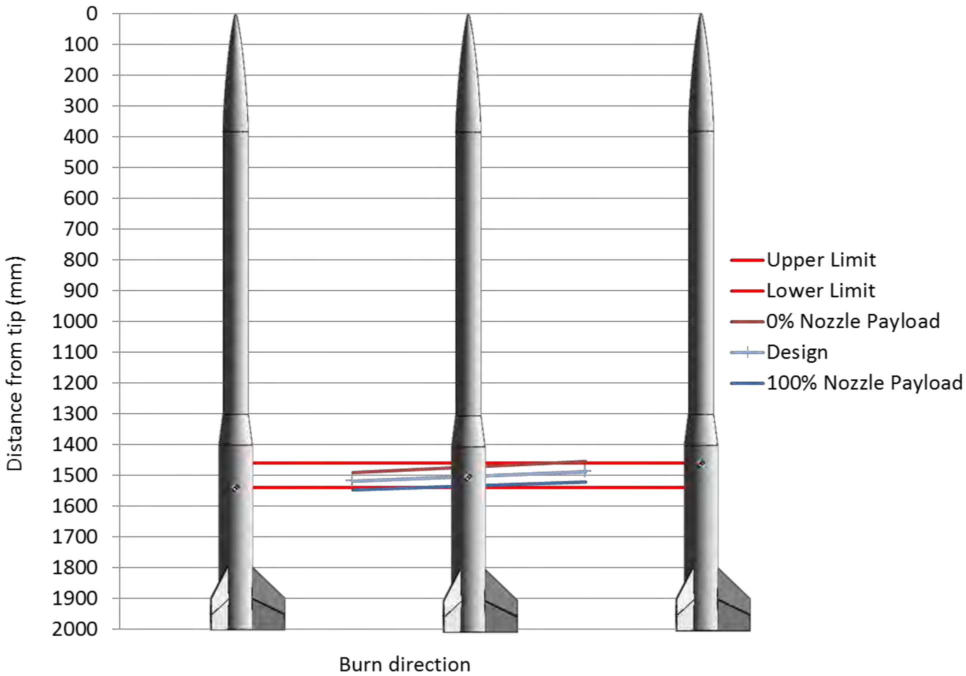

Figure 11. Designed Center of Gravity inside the finset limits for a statically stable rocket

7. ENGINEERING MODEL FLIGHT

After manufacturing all *hard* parts of the rocket (excluding all electronics and avionics), the ITA Rocket Design team tested it's Engineering Model in a flight near São José dos Campos, São Paulo, Brazil, on June 1st. This test consisted in a low powered flight, with less propulsive energy so the maximum altitude wouldn't interfere with airspace traffic.

This test required a lot of the group's effort to build its own launch rail, a 4 meters tall structure with elevation and azimuth control, to find a good place for the test and to transport all the parts to the place for integration and launching. This last problem partially simulates the difficulties found when transporting the rocket parts through the high controlled American customs.

Unfortunately the conditions of launching in Brazil is very different from the one found in the USA. The first obvious difference is the seasons: while in Brazil it was winter, with a tropical cold and humid weather with no winds, in USA it was summer, with a desert hot and dry weather with high winds. The second difference is about the location: in Brazil it was in the Paraíba Valley, surrounded by mountains covered by dense vegetation, while in the USA it was in a plain near the Rocky Mountains, which allows a good vision range to track the rocket after launching.

Even with those differences, this test is very important to train the team's readiness and to acknowledge the minor last hour difficulties normally found in the pre-launch operation. The flight, on the aerodynamic and stability point of view, was a success: even with the rocket leaving the launch rail with low speed, the finset could stabilize the rocket flight in its pathway.

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Figure 12. Engineering flight snapshots

Figure 13. Reduction of the angle of attack due to the fin aerodynamic stabilization

Figure 12 shows three sequential snapshots of the launch that reached about 100 m. As can be seen in the details at Figure 13, the rocket suffered from an initial deviation, probably because of its low speed and the interference of the launch rail. This made the rocket to change its elevation angle from the red line to the black line. But, as it continued its pathway up with a negative angle of attack, the fins successfully worked to bring this angle back to zero. At the third picture it can be seen the new pathway in yellow, closer to the initial red one. Of course the faster is the rocket the stronger is the fin effect. So it's expected the real rocket would be even more stable.

8. COMPETITION FLIGHT

During competition there are two days for the rocket launching. At 8th IREC they were on the sunny days of June 21 and 22. The rocket launch order follows the first in - first out logic. As exposed in the section 3, the ITA Rocket Design team worked hard to launch during the morning, to avoid the early afternoon winds. The launch checklist sequence started at 6:00 am of the second day. This sequence consisted of the integration of the payload part over the motor part at the city workstation, the careful transport of the whole rocket to the launch site, its positioning on the launch rail, the initialization of the electronics devices, the positioning of the igniter and, finally, the launch countdown. The flight happened exactly at 08:01 am. As expected, compared to the afternoon weather, there was almost no wind at ground level. The flight was nominal, with a small deviation at the upper atmospheric layers, as can be seen at Figure 14. After gaining enough speed, the rocket stability stopped the deviation and recovered the ascension, shown in yellow.

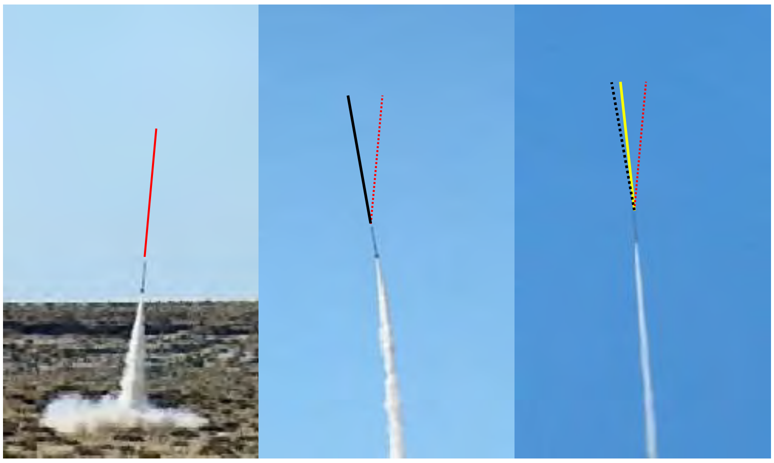

Figure 14. Deviation and recovery of the flight path during the 8th IREC

Once again, the rocket motor wasn't strong enough to give the necessary speed during the first moments of the flight. This allowed the rocket to change its initial path at the beginning, but, after reaching a more expressive speed, the rocket kept itself stable through the rest of the flight. It was clear that the rocket accelerates more and more throughout the burning time for two main reasons: the thrust is higher near the end of the burning time because of the cylindrical grain, and at this moment the whole rocket is lighter because of the negative mass flux passing through the nozzle. So the peak velocity is reached only after some meters away the launch rail, what demonstrate the critical importance on launching in nearly no wind condition. After reaching its full velocity, the wind influence on the rocket is negligible.

During the pre-tests of the rocket motor made at the United States, it was realized that the potassium nitrate found there wasn't pure enough to give the rocket all the power needed to reach the targeted altitude. Also, because of its high overall empty mass, of 15.3 kg, and the low specific impulse of the propellant used, of 140 s, the rocket apogee was only 1 km, below the required 10 000 feet. But, as the only team using a student designed and built rocket, including its motor, this flight, which was recovered, demonstrated the full potential of the team's capabilities. With these results, the ITA Rocket Design team won the Jim Furfaro Award for Technical Excellence. This prize is given to the team with the best overall rocket design from both categories (the basic – 10000 feet – and the advanced – 25000 feet).

9. FUTURE PERSPECTIVES

It's clear that a more powerful motor, especially during the flight first moments, would help the rocket stability. The team's propulsion group is now aware to look for propellants with best quality and, if possible, change the inner geometry of the grain. Another way to attack the acceleration problem is reducing the rocket empty mass. The team's structure group will try to produce carbon fiber instead of buying aluminum tubes. At last, the aerodynamic group will finally integrate and complete the fight dynamic prediction software. With that, the team will have more accurate predictions of the range and dispersion of the launched rocket.

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