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Risk Analysis Comparison between the Mission NANOSATC-BR1 and NANOSATC-BR2

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Abstract: The goal of this work is to perform the risks analysis of the mission NANOSATC-BR1 and NANOSATC-BR2 and then compare them linearly. The NANOSATC-BR1 and NANOSATC-BR2 are the first and the second satellite, respectively. They belonged to the project NANOSATC-BR—development of CubeSats, which is performed in the facilities built by the partnership between the National Institute of Space Research and the Technological Center from Federal University of Santa Maria. The project focuses on the development of a scientific instrumentation and, simultaneously, the design development, construction, qualification and launch of a national scientific nanosatellite, in a cube shape with 100 mm of edge and near to 1.33 kg of mass, per unit (U). The risk analysis was held to identify and minimize the project's risks of failure, due to its complexity, assuring the mission success, preventing extra pays and rework. The software, CubeSat Mission Design Software Tool for Risk Estimating, which uses statistical regression methods, was used. So, we were capable to measure the project's most critical steps assuring its success. The NANOSATC-BR1 was launched in June 19 and it is orbiting the Earth in a nominal regime and the NANOSATC-BR2 has been scheduled to be launched in 2016.

Key words: Analysis, risk, CubeSat.

1. Introduction

The program NANOSATC-BR—development of CubeSats has the NCBR1 and the NCBR2 as its very first nanosatellites, both on the CubeSat standard. This nanosatellite class has, per unit (U), a cube shape with 100 mm of edge and near 1.33 kg of mass, as minimum specifications. Both are composed by:

- mechanical structure;
- systems;
- subsystems;
- payload (scientific and technologic).

The NANOSATC-BR1 in Fig. 1 is the first Brazilian scientific university nanosatellite, and thus meets all specifications of the CubeSat (1 U) class. The NCBR1 has the scientific mission of collecting data through a magnetometer (XEN-1210 model, with resolution 15nT) of the terrestrial magnetic field, mainly on the South American Magnetic Anomaly. However, the technologic mission is to test, during the flight, the radiation resistance of ICs (integrated

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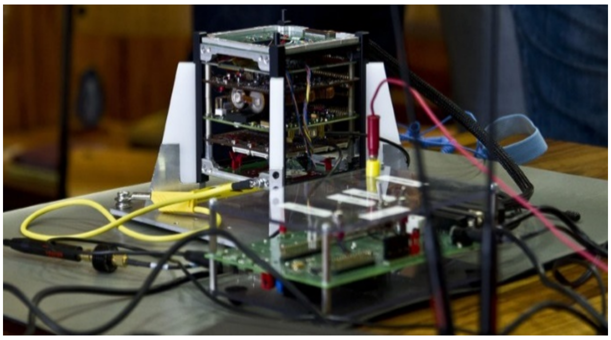

Fig. 1 NANOSATC-BR1: engineering model.

circuits) designed in Brazil, being one FPGA (Field Programmable Gate Array) chip developed by UFRGS (Federal University of Rio Grande do Sul) and a drive chip developed by SMDH (Santa Maria Design House), validating it for future use in Brazilian space missions with larger satellites. The 1 U CubeSat—NANOSATC-BR1, was launched into a LEO (Low Earth Orbits) orbit from the Russian Yasny Launch Base by a DNEPR (DNEPR is the rocket baptized name as the Ukrainian river in Dnepropetrovsk)) launch vehicle on June 19, 2014, and it is orbiting the Earth in nominal and safe modes.

The NANOSATC-BR2 in Fig. 2 is the second Brazilian scientific nanosatellite from the program and fits the CubeSat (2 U) class, thus meeting all specifications of the CubeSat class. The NCBR2's scientific mission focuses on using a Langmuir probe to capture data from the ionosphere region, referring to the amount of plasma material present in this region. However, the technologic mission aims to validate the first national system for attitude determination (triple redundancy). The NANOSATC-BR2 is on a very advanced development stage and its launching date is schedule for the end of 2015.

Even when dealing with low-cost space missions, it does not dispense conducting a risk analysis to minimize the subjectivity of the risk evaluation of each stage of the project. The comparison is made linearly between NCBR1 and NCBR2 after conducting the risk analysis of the two nanosatellites.

The paper is organized as follows: Section 2 discusses the methodology used to develop this studies; Section 3 presents results and discussions; and Section 4 gives conclusions.

Fig. 2 NANOSATC-BR2: engineering model.

2. Methodology

For the realization of the NCBR1 and NCBR2 mission's risk analysis, we used the software CubeSat Mission Design Software Tool for Risk Estimating Relationships, which provide us, numerically and graphically, through the "Likelihood X Consequence" relation, data of several risks involving each missions. This software is based on several historical source of risks association to smaller space projects (CubeSats), and, using statistical regression methods, it is capable to identify the risks involving each project.

By using this software, we reduce the subjectivity of the project's risk evaluation, thus, being able to recover resources and develop techniques to mitigate the project's threats.

The sectors evaluated are divided into:

- schedule;
- payload;
- SpaceCraft-1—communication;
- SpaceCraft-2—service subsystem and mechanic structure;
- SpaceCraft-3—mission and orbit;
- personnel—work group (information);
- Cost.

First, we raise several temporal nature data from both missions; therefore, we can fill out the software input (Fig. 3).

Related to temporal data used in the software, we could choose whether it would be "actual" for data that had already occurred, or "predicted" for data that were only expected to occur.

In Fig. 4, the "months S/C is in operations" is the only item classified as "predicted" for the NCBR1, since the operational period of the nanosatellite is estimated for 36 months. The same happens to the NCBR2.

Parameter	Description
Form factor	*Enter a numeric value corresponding to the number of U's your spacecraft design uses (e.g. 3U would be entered as "3")*
Mass	*Enter a numeric value of the mass limit (in kg)*
Launched?	*Select an answer using the drop-down menu: Yes, the s/c has launched; No, but we've been manifested; No, but we have a launch promised (ELaNa or similar); No, we have not been manifested or given a promise of*
Launch Date	*Give the date of the launch; If the s/c has yet to be launched, give the projected date. (Can be in MM/DD/YYYY or MM/YYYY or YYYY format)*
Months in Development	*Enter a numeric value corresponding to the number of months in s/c design and development, including everything up until flight integration; Indicate whether this value is actual or predicted*
Months in Integration	*Enter a numeric value corresponding to the number of months taken for s/c integration; Indicate whether this value is actual or predicted*
Months in S/C Functional Testing	*Enter a numeric value corresponding to the number of months spent on integrated s/c testing at the organization level, including functional testing; Indicate whether this value is actual or predicted*
Months in S/C Environmental Testing	*Enter a numeric value corresponding to the number of months spent on necessary testing to satisfy launch provider requirements (usually includes thermal vac, vib tables, and mass properties testing); Indicate whether this value is actual or predicted*
Months S/C is awaiting launch	*Enter a numeric value corresponding to the number of months the spacecraft was "on the shelf" waiting for launch after all testing had been completed; Indicate whether this value is actual or predicted*
Months S/C is in operations	*Enter a numeric value corresponding to the number of months the spacecraft was operational in orbit; Indicate whether this value is actual or predicted*
Milestone	*Enter the name of the milestone for which these numbers reflect the status*

Fig. 3 Software input's interface.

Parameter	Input	Actual or Predicted?
Form factor	1	
Mass	0,98	
Launched?	Yes, the s/c has been launched	
Launch Date	2014	
Months in Development	24	Actual
Months in Integration	0,5	Actual
Months in S/C Functional Testing	1	Actual
Months in S/C Environmental Testing	0,5	Actual
Months S/C is awaiting launch	2	Actual
Months S/C is in operations	36	Predicted
Milestone	NCBR1	

Fig. 4 NANOSATC-BR1's input data.

Parameter	Input	Actual or Predicted?
Form factor	2	
Mass	2,5	
Launched?	No, but we've been manifested	
Launch Date	2015	
Months in Development	24	Predicted
Months in Integration	0,5	Predicted
Months in S/C Functional Testing	1	Predicted
Months in S/C Environmental Testing	0,5	Predicted
Months S/C is awaiting launch	2	Predicted
Months S/C is in operations	36	Predicted
Milestone	NCBR2	

Fig. 5 NANOSATC-BR2's input data.

In Fig. 5, it has all items classified as "predicted" because the NCBR2 project is still in early development.

The inputs of both missions are relatively equal in the category AIT (assemble, integration and tests). This similarity in periods of AIT is because this process is relatively the same for both nanosatellites; thereby, we have a greater linearity on risk analysis comparison.

Through numerical results (probability/consequence) after the first step, we compared the risks of both missions. The software also provided a graphic "Probability X Consequence", helping visual comparison.

After thoroughly analyzing each sector evaluated by the software, we classify the most critical risks for each project. These results will be presented later.

3. Results and Discussions

The analysis has begun with NANOSATC-BR1, CubeSat 1 U, which is already on space.

First, the "Probability X Consequence" graphic is shown in Fig. 6.

Analysis of NANOSAC-BR2, nano-satelite 2 U CubeSat, is scheduled for release in 2015.

Milestone 1	C	L
SCH	1,7	4,24
PER	1,67	3,84
PAY	2,18	3,2
SC-1	2,3	3,57
SC-2	2,38	3,1
SC-3	2,2	3,39
COST	1,52	3,16

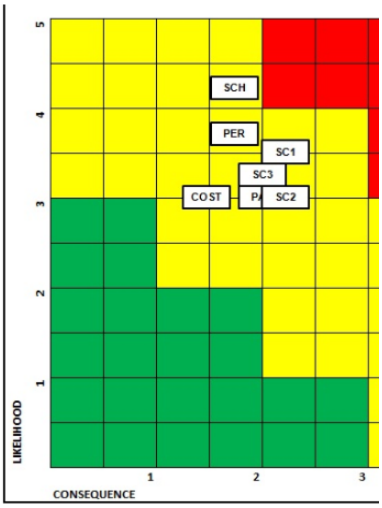

Fig. 6 "Probability X Consequence" NANOSATC-BR1's graphic. "Schedule" shows the same position as "cost".

A	B	C	D
		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
Schedule		1,696513891	4,238957114
	1. Inability to find desired spacecraft components	0,246669841	4,45119265
	2. Mechanical design delays (such as issues with the CAD or drawings)	1,032846906	4,480374368
	3. Software design delays (such as basic component functionality or embedded coding issues)	2,500356386	4,511971017
	4. Delay due to issue with payload provider (may be related to delivery of EDU or flight unit, documentation, or interface issues)	1,076395997	4,234666036
	5. Delay due to inadequate documentation	1,79517698	2,5
Payload		2,178759352	3,19700759
	1. Software interface issues between payload and spacecraft bus	2,865447087	3,203349516
	2. Hardware/electrical interface issues between payload and spacecraft bus	1,153552615	3,719112978
	3. Payload malfunction due to mechanical issues	2,148226655	3,235450504
	4. Payload malfunction due to software issues	0,860016123	2,398613544

Fig. 7 Numerical risk value of "schedule" and "payload" for the NCBR1.

Fig. 11 shows the "Probability X Consequence" of the NCBR2.

The following numerical results follow with a straight comparison between the two missions.

By making the results analysis frameworks of NCBR1 in Fig. 7 and NCBR2 in Fig. 12, it is attested that the probability that an anomaly has occurred with the schedule NANOSATC-BR1 is higher, especially regarding to design of software (basic functionality of components or programming problems) delay.

Nevertheless, the consequence of an error in this

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
SC-1		2,300582521	3,569160663
	1. No frequency on which to communicate with spacecraft due to delay in receiving frequency allocation	2,997108773	5
	2. Failure of spacecraft radios (due to either hardware or software issues)	1,300362705	2,534981693
	3. Failure of spacecraft antennas due to improper deployment or activation	1,379424677	2,455842069
	4. Failure of ground station radios (due to either hardware or sofware issues)	2,195037729	3,177889014
	5. Failure of ground station antennas (due to either hardware or software issues)	1,867351081	0,541397799
SC-2		2,382306875	3,1022584
	1. Failure of flight computer(due to either hardware or software issues)	2,5	2,31424237
	2. Failure of sensors gathering health data (due to either hardware or software issues)	2,771341261	3,897578292
	3. Failure of actuators causing unstable spacecraft motion (due to eitehr hardware or software issues)	1,745391145	2,295657155
	4. Failure of power regulation/battery system (due to either hardware or software issues)	1,170694044	2,475755378
	5. Failure of solar panels to generate power (due to either hardware or software issues)	2,368002965	3,484830399
	6. Unexpected thermal enviornment caused system issues	2,307876242	2,181654991
	7. Unexpected vibration enviornment caused system issues.	1,770096139	1,644484311

Fig. 8 Numerical risk value of "SpaceCraft-1" and "SpaceCraft-2" for the NCBR1.

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
SC-3		2,198216307	3,385387163
	1. Spacecraft will not de-orbit within 25 years after end-of-life	1,094290318	3,686915656
	2. Spacecraft bus does not meet in-house requirements (i.e. dimension, mass limits, structural/thermal anaylses)	2,556475149	3,338588149
	3. Spacecraft does not meet on-orbit launch and release mechanism provider requirements (i.e. waiting to beacon and deploy antenna)	2,710678248	3,29564429
	4. Mission does not supply required documentation as requested by launch and release mechanism	0,903752175	3,435918689
PER		1,673088982	3,843051008
	1. Loss of information (due to configuration management issues or computer malfunction)	2,06103012	4,562550813
	2. Loss of hardware (perhaps due to uncontrolled access to lab enviornment and hardware)	0,760213661	0,481001209
	3. Lack of sufficient training for team members completing flight qualification necessary tasks	1,333639716	3,824076839
	4. Attrition or turnover of team members	1,304223706	3,679990517
	5. Sudden loss of crucial team members (due to either personal or work/school reasons)	1,904445512	3,792379079

Fig. 9 Numerical risk value of "SpaceCraft-3" and "personnel" for the NCBR1.

COST		1,523903644	3,155312099
	1. Incomplete understanding of the projected total mission cost	1,879521435	3,905067137
	2. COTS component price increases	0,606304449	2,90785484
	3. Inability to obtain new research grants or funding	0	0,518338063
	4. Delay of receiving promised funding	2,18635268	3,13926055

Fig. 10 Numerical risk value of "cost" for the NCBR1.

Milestone 1	C	L
SCH	2,36	3,84
PER	1,3	3,18
PAY	2,03	3,07
SC-1	2,13	3,23
SC-2	2,59	2,9
SC-3	1,63	2,14
COST	2,27	3,68

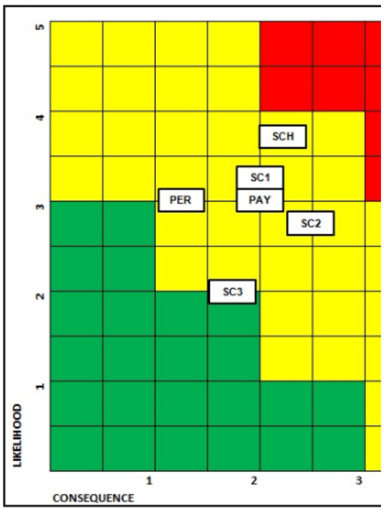

Fig. 11 "Probability X Consequence" NANOSATC-BR2's graphic.

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
Schedule		2,36217467	3,836678231
	1. Inability to find desired spacecraft components	0,675833137	3,440439817
	2. Mechanical design delays (such as issues with the CAD or drawings)	0,467773182	4,08043373
	3. Software design delays (such as basic component functionality or embedded coding issues)	2,278525646	4,634787229
	4. Delay due to issuse with payload provider (may be related to delivery of EDU or flight unit, documentation, or interface issues)	2,928932407	3,933491645
	5. Delay due to inadequate documentation	3,18877204	2,5
Payload		2,02541531	3,072741583
	1. Software interface issues between payload and spacecraft bus	2,40310252	3,326052666
	2. Hardware/electrical interface issues between payload and spacecraft bus	0,818597361	3,68870165
	3. Payload malfunction due to mechanical issues	2,324675108	3,043852779
	4. Payload malfunction due to software issues	1,525237476	1,295994771

Fig. 12 Numerical risk value of "schedule" and "payload" for the NCBR2.

sector, especially concerning delays due to delayed documentation, is higher in NANOSATC-BR2, since it is still under development.

According to the graphic generated by the software, both the nanosatellites payloads have relatively the same risk. However, after evaluating the numerical results, we found that the probability of an error in the interface between the payload and the spacecraft or the electrical part of the payload occurs, was higher in NCBR1. The probability of an abnormality in the payload due to the mechanical (structural) or software failures is greater in NCBR2. The consequence for a failure in this sector was considered equal for both nanosatellites.

The analysis is done by comparing Figs. 8 and 13.

In relation to "SC-1", it has been concluded that NCBR1 has "Probability X Consequence" higher than any other failure in this sector. A risk towards maximum probability was found (grade: 5), referred to lacking of nanosatellite internal systems communication frequency and as conclusion it has shown higher risk on Consequence.

NCBR1 has presented higher probability of error on the mechanical structure and services models sector, which the critical case is the failure on data collects sensors. In case of any NCBR2 anomaly, its consequence would be higher, mainly in battery/energy failure system sector.

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
SC-1		2,131955459	3,226776124
	1. No frequency on which to communicate with spacecraft due to delay in receiving frequency allocation	2,085695988	4,154047166
	2. Failure of spacecraft radios (due to either hardware or software issues)	2,160066331	2,782126697
	3. Failure of spacecraft antennas due to improper deployment or activation	1,972371867	2,462600152
	4. Failure of ground station radios (due to either hardware or sofware issues)	2,177519859	2,270970959
	5. Failure of ground station antennas (due to either hardware or software issues)	2,29014442	2,287296598
SC-2		2,585717147	2,904289151
	1. Failure of flight computer(due to either hardware or software issues)	1,966278695	2,585863912
	2. Failure of sensors gathering health data (due to either hardware or software issues)	2,748401396	3,234244496
	3. Failure of actuators causing unstable spacecraft motion (due to eitehr hardware or software issues)	2,628067353	2,486290951
	4. Failure of power regulation/battery system (due to either hardware or software issues)	2,822203674	2,164672139
	5. Failure of solar panels to generate power (due to either hardware or software issues)	2,433881905	2,946321788
	6. Unexpected thermal enviornment caused system issues	2,427238149	2,991610041
	7. Unexpected vibration enviornment caused system issues.	2,572357238	2,366002763

Fig. 13 Numerical risk value of "SpaceCraft-1" and "SpaceCraft-2" for the NCBR2.

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Likelihood value
SC-3		1,631995468	2,138860406
	1. Spacecraft will not de-orbit within 25 years after end-of-life	1,548270072	2,020357378
	2. Spacecraft bus does not meet in-house requirements (i.e. dimension, mass limits, structural/thermal anaylses)	1,64304881	2,248610192
	3. Spacecraft does not meet on-orbit launch and release mechanism provider requirements (i.e. waiting to beacon and deploy antenna)	1,75486147	2,135478437
	documentation as requested by launch and release mechanism providers	1,230058636	2,090892751
PER		1,301731352	3,175865159
	1. Loss of information (due to configuration management issues or computer malfunction)	1,773351551	3,386076544
	2. Loss of hardware (perhaps due to uncontrolled access to lab enviornment and hardware)	0	0
	3. Lack of sufficient training for team members completing flight qualification necessary tasks	0,139678006	3,407661924
	4. Attrition or turnover of team members	1,46021017	3,90989007
	5. Sudden loss of crucial team members (due to either personal or work/school reasons)	1,935652686	2,898571563

Fig. 14 Numerical risk value of "SpaceCraft-3" and "personnel" for the NCBR2.

Considering the numerical values of Figs. 9 and 14, we conclude that the NCBR1 risk related to the orbit and mechanics has "Probability" is mainly related to "Spacecraft that will not get out of orbits within 25 years", and "Consequence", especially in the area "It not meet the requirements in Mechanical during its Orbit", is greater than the risk of NCBR2.

The NCBR1 also has higher "Probability", mainly in the lack of training of the working group, and "Consequence", especially in the area of lack of information management, than NCBR2 in working group sector.

Regarding "mission costs" in Figs. 10 and 15, the NCBR2 is much more vulnerable, since the "Probability" mainly in "components cost increasing" and the "Consequence", especially in "delay in the receiving of financial resources for the project" are the greatest risks for NCBR1.

In Fig. 16, it follows the comparison done through the software between NANOSATC-BR1 (Milestone 2) and NANOSATC-BR2 (Milestone 3).

After analyzing all missions sectors, the Probability and Consequence items were processed. These two items are shown in Table 1.

COST		2,266449009	3,683237925
	1. Incomplete understanding of the projected total mission cost	2,356111174	3,954890385
	2. COTS component price increases	1,019469452	4,183909558
	3. Inability to obtain new research grants or funding	0,401111695	2,065082367
	4. Delay of receiving promised funding	3,103612107	3,78506004

Fig. 15 Numerical risk value of "cost" for the NCBR2.

Milestone 2	C	L
SCH	1,697	4,239
PER	1,673	3,843
PAY	2,179	3,197
SC-1	2,301	3,569
SC-2	2,382	3,102
SC-3	2,198	3,385
COST	1,524	3,155

Milestone 3	C	L
SCH	2,362	3,837
PER	1,302	3,176
PAY	2,025	3,073
SC-1	2,132	3,227
SC-2	2,586	2,904
SC-3	1,632	2,139
COST	2,266	3,683

Fig. 16 Comparison between the two missions.

Table 1 Total risks numerical value of both missions.

	NCBR1	NCBR2
Probability	24,490	22,039
Consequence	13,954	14,305

We have defined and analyzed that the Probability of risk for NCBR1 is greater than NCBR2, nevertheless, the Consequences of these risks for NCBR2 is greater.

4. Conclusions

It is concluded from the risk analyses of NANOSATC-BR missions that the "SCH", schedule, was identified as the greatest risk sector for both projects, thus, an extra attention must be required, regarding the current NCBR1 step and future NCBR2 step. Furthermore, for NCBR1, the lower risky sector is "cost" and for NCBR2 is "SC-3" (mechanics and orbit).

Therefore, the risk analyses are attested as mandatory for CubeSat missions, since the missions complexity is increasing with the time.

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