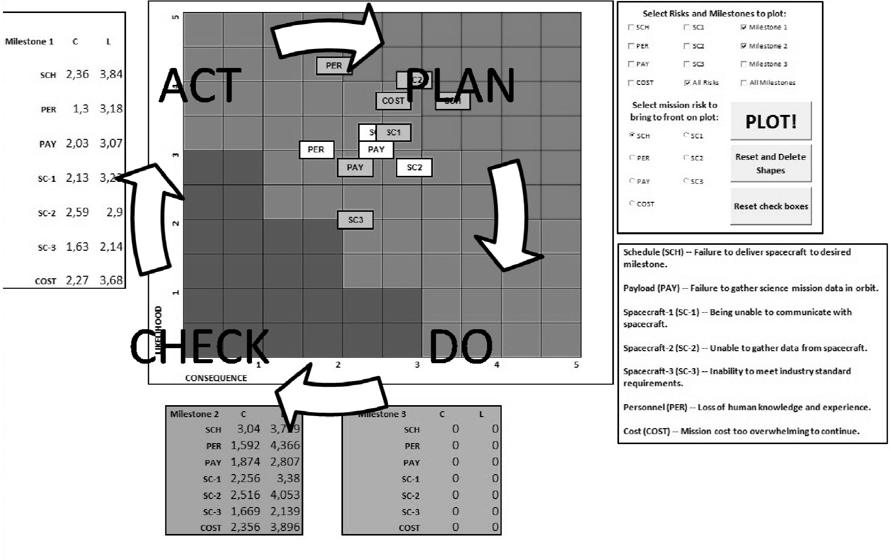

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Applicable Solution for Optimizing Critical Points on Nanosatelite Missions - NANOSATC-BR, CubeSats Development Program

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The main goal of this paper is to show possible applicable improvements in the milestone of nanosatellites, based on critical points that

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were identified in both NANOSATC-BR1 and NANOSATC-BR2 missions, reducing and optimizing them in order to enhance mission performance by lowering risks levels. To support this analysis, the PDCA Methodology is used. The V Model – from System Engineering – will be used in this case as well because of its architecture, which has the capability of verifying what is being built with what was defined, to guarantee that the mission stakeholders will be fulfilled. Analyzing the obtained risk analysis data, solutions are presented with the objective to reduce risks, in specified parts of nanosatellites milestone in order to get a better result with less changes. The nanosatellites analyzed are the NANOSATC-BR1 – which has already completed one and a half year in operation on space - and the NANOSATC-BR2, both of them from the NANOSATC-BR - CubeSats Development Program. This Program aims to improve and capacitate building of human resource by designing, developing payloads and platforms, test, launch and operate national scientific satellite in CubeSat standards. The Program has been designed and executed in a partnership between the Southern Regional Space Research Center (CRS) from the National Institute of Space for Space Research (INPE – MCTI) and Santa Maria Space Science Laboratory (LACESM), from the Federal University of Santa Maria (UFSM).The program has aid and support from the Brazilian Space Agency (AEB).

Introduction:

The NANOSATC-BR, CubeSats Development Program has two nanosatellites, both from CubeSat standards – the minimum size for this category is a 1U, which is a cube with 100 mm of edge and, at maximum, 1.33 Kg in mass. The first nanosatellite of the program is the NANOSATC-BR1 (or abbreviated as NCBR1), which is an 1U CubeSat that fulfills all the requirements to fit in the CubeSat category, and its scientific mission is to get data from a magnetometer from the Earth magnetic field – specially from SAMA – South American Magnetic Anomaly – and from the Equatorial Ionospheric Electrojet. Its technologic mission is to test integrated circuits (both developed in Brazil) resistance due to the radiation [1]. NCBR1 is currently transmitting data from its payloads for more than eighteen months.

The second satellite – waiting for launch – is the NANOSATC-BR2, which is a Two Unit CubeSat (2U), (NCBR2), and has as one of its most important scientific missions to analyze the dynamics of the Ionosphere plasma using a Langmuir Probe. Regarding the technologic missions, one of them consists in validate an attitude control system – the very first Brazilian one – with triple redundancy.

With the objective of improving future CubeSats missions, the PDCA methodology was used to provide better results to the process. Working with mission risks analysis and critical points found in the process [2], the parts of the mission with higher risks – critical points – are analyzed in each context and suggestions are made to correct – or minimize – them.

Methodology:

One PDCA cycle was made for each mission. The PDCA cycle is a continuous management methodology to improve processes and products with four basic steps, being them Plan (P), Do (D), Check (C) and Act (A), Fig. 1. Initially, the first step is to define what the objective is and how to achieve it. The second phase is used to do what was defined in Plan phase. Next step is to Check and analyze the new situation – after being made changes in Do – and compare with the previous situation. In the end, Act is used to determine if what was done in Do improved the system – then keep it – or made it worst [3].

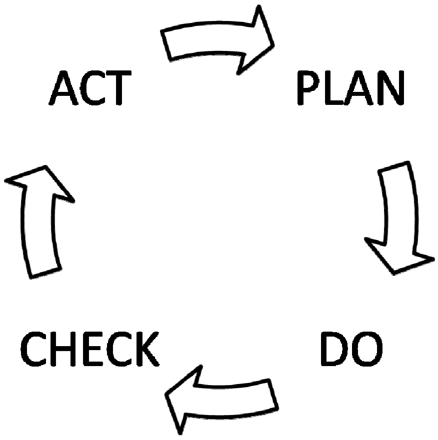


Fig. 1. PDCA Cycle

To enhance explanation when improvements suggestions are made, it was used the V Model from System Engineering, Fig. 2, due to its capability of describing the steps from the program development and the interactions between them [4].

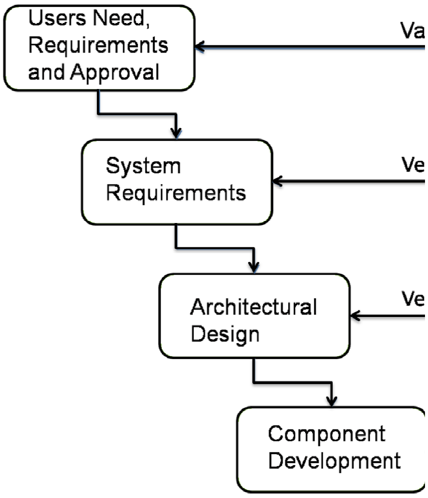
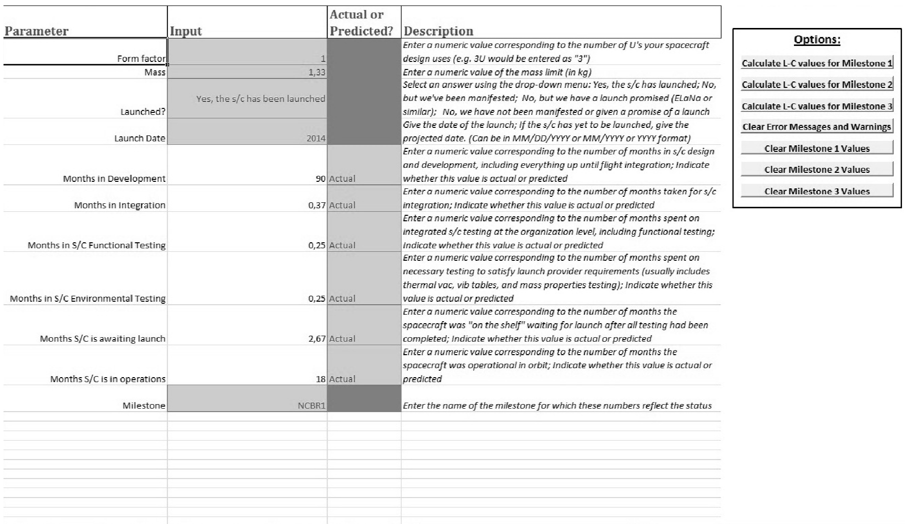


Fig. 2. Shows V Model

The PDCA was used as follow:

Plan – The objective is reduce critical mission risks – critical points – to improve the rate of success in future missions, Fig. 3.
Do – In Do, data from the missions were collected, and then the software was used to get new risk analysis, Fig. 4. The risks were obtained using the CUBESAT MISSION DESING SOFTWARE TOOL FOR RISK ESTIMATING [5] software (it uses based recorded missions and statistics regression methods to identify missions risks), Fig. 5.



Parameter	Input	Actual or Predicted?	Description
Form factor	1		Enter a numeric value corresponding to the number of U's your spacecraft design uses (e.g. 3U would be entered as "3")
Mass	1,33		Enter a numeric value of the mass limit (in kg)
Launched?	Yes, the s/c has been 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 a launch
Launch Date	2014		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	90	Actual	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	0,37	Actual	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	0,25	Actual	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	0,25	Actual	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	2,67	Actual	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	18	Actual	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	NCBR1		Enter the name of the milestone for which these numbers reflect the status

Options:
Calculate L-C values for Milestone 1
Calculate L-C values for Milestone 2
Calculate L-C values for Milestone 3
Clear Error Messages and Warnings
Clear Milestone 1 Values
Clear Milestone 2 Values
Clear Milestone 3 Values

Fig. 3. Inputs from current data for NCBR1

		Milestone 1	
Mission Risk	Root Cause	Consequence value	Like v
Schedule		3,295941432	
	1. Inability to find desired spacecraft components	5	
	2. Mechanical design delays (such as issues with the CAD or drawings)	1,691301703	
	3. Software design delays (such as basic component functionality or embedded coding issues)	1,792366165	
	4. Delay due to issuse with payload provider (may be related to delivery of EDU or flight unit, documentation, or interface issues)	2,5	
	5. Delay due to inadequate documentation	1,319370801	
Payload		2,40062283	
	1. Software interface issues between payload and spacecraft bus	2,865447087	
	2. Hardware/electrical interface issues between payload and spacecraft bus	0,673880045	
	3. Payload malfunction due to mechanical issues	2,15214139	
	4. Payload malfunction due to software issues	2,5	
SC-1		2,666522247	
	1. No frequency on which to communicate with spacecraft due to delay in receiving frequency allocation	2,997108773	
	2. Failure of spacecraft radios (due to either hardware or software issues)	2,5	
	3. Failure of spacecraft antennas due to improper deployment or activation	2,5	
	4. Failure of ground station radios (due to either hardware or sofware issues)	2,5	
	5. Failure of ground station antennas		

Fig. 4. Risks Analysis for current data for NCBR1

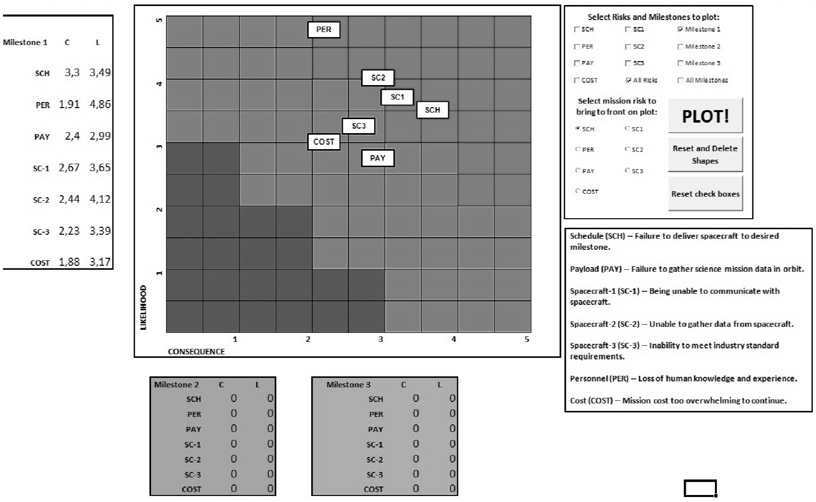


Fig. 5. Risks for NCBR1 mission in Consequences x Likelihood graph

Check – For comparison, the software CUBESAT MISSION DESING SOFTWARE TOOL FOR RISK ESTIMATING was useful due to its capability of using more than one mission data, side by side, Fig. 6. Using other identified mission critical points with the new risk analysis from Do step, a graph was created showing both analyses. The graph shows Consequenses x Likelihood (Fig. 7.).

		Milestone 1		Milestone 2		Milestone 3	
Mission Risk	**Root Cause**	**Consequence value**	**Likelihood value**	**Consequence value**	**Likelihood value**	**Consequence value**	**Likelihood value**
Schedule		3,295864811	3,491851693	1,696513891	4,238957114		
	1. Inability to find desired spacecraft components	5	2,5	0,246669841	4,45119265		
	2. Mechanical design delays (such as issues with the CAD or drawings)	1,69119325	5	1,032846906	4,480374368		
	3. Software design delays (such as basic component functionality or embedded coding issues)	1,792327093	3,629447882	2,500356386	4,511971017		
	4. Delay due to issuse with payload provider (may be related to delivery of EDU or flight unit, documentation, or interface issues)	2,5	4,798065456	1,076395997	4,234666036		
	5. Delay due to inadequate documentation	1,318725646	2,5	1,79517698	2,5		
Payload		2,387632869	2,994097355	2,178759352	3,19700759		
	1. Software interface issues between payload and spacecraft bus	2,865447087	3,11835673	2,865447087	3,203349516		
	2. Hardware/electrical interface issues between payload and spacecraft bus	0,565643582	3,176494956	1,153552615	3,719112978		
	3. Payload malfunction due to mechanical issues	2,152131485	2,116208361	2,148226655	3,235450504		
	4. Payload malfunction due to software issues	2,5	3,239639132	0,860016123	2,398613544		
SC-1		2,666356105	3,650713367	2,300582521	3,569160663		
	1. No frequency on which to communicate with spacecraft due to delay in receiving frequency allocation	2,997108773	5	2,997108773	5		
	2. Failure of spacecraft radios (due to either hardware or software issues)	2,5	1,99243486	1,300362705	2,534981693		
	3. Failure of spacecraft antennas due to improper deployment or activation	2,5	2,060122833	1,379424677	2,455842069		
	4. Failure of ground station radios (due to either hardware or sofware issues)	2,5	3,177889014	2,195037729	3,177889014		
	5. Failure of ground station antennas						

Fig. 6. Shows in Milestone 1 risk analysis from NCBR1 with old data and in Milestone 2 risks analysis for NCBR1 with current data.

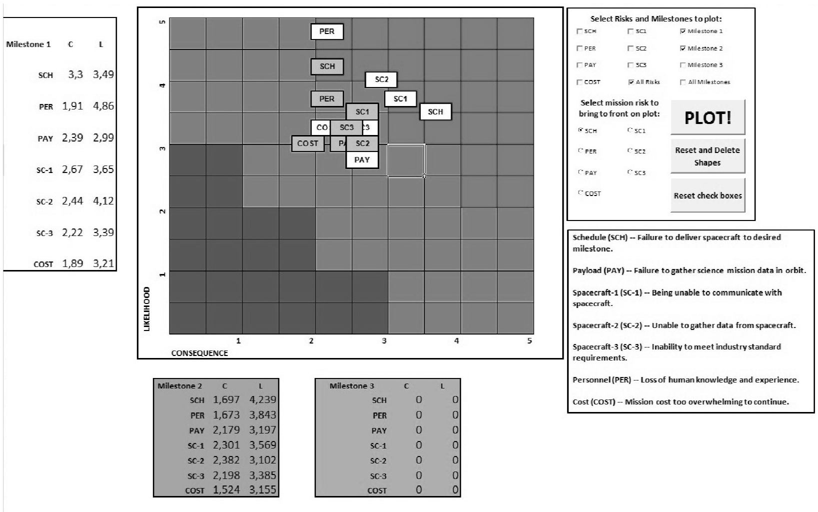


Fig. 7. Shows in the graph Consequence x Likelihood the risks from the two data for NCBR1.

Act – Suggestions to ease critical points, based on current situation the mission is facing, were introduced.

This four-step process was made firstly for NCBR1 and right after for NCBR2, allowing better analysis on critical points, Fig. 8 and Fig. 9.

Parameter	Input	Actual or Predicted?	Des
Form factor	2		Enter desig
Mass	2,5		Enter
Launched?	No, but we've been manifested		Select but w simila
Launch Date	2016		Give t proje
Months in Development	53	Predicted	Enter and d wheth
Months in Integration	0,37	Predicted	Enter integr
Months in S/C Functional Testing	0,25	Predicted	Enter integr Indica
Months in S/C Environmental Testing	0,25	Predicted	Enter neces therm value
Months S/C is awaiting launch	4	Predicted	Enter space comp
Months S/C is in operations	12	Predicted	Enter space predic
Milestone	NCBR2		Enter

Fig. 8. Inputs for NCBR2 with current data.

		Milestone 1		Milestone 2		Milestone 3	
Mission Risk	Root Cause	Consequence value	Likelihood value	Consequence value	Likelihood value	Consequence value	Likelihood value
Schedule		2,36217467	3,836678231	3,040120281	3,729373972		
	1. Inability to find desired spacecraft components	0,675833137	3,440439817	5	2,5		
	2. Mechanical design delays (such as issues with the CAD or drawings)	0,467773182	4,08043373	1,532835752	4,0621655		
	3. Software design delays (such as basic component functionality or embedded coding issues)	2,278525646	4,634787229	2,012212419	3,884419208		
	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	3,051571062	4,455056125		
	5. Delay due to inadequate documentation	3,18877204	2,5	1,680452515	2,5		
Payload		2,02541531	3,072741583	1,87353311	2,807029123		
	1. Software interface issues between payload and spacecraft bus	2,40310252	3,326052666	2,40310252	3,275505489		
	2. Hardware/electrical interface issues between payload and spacecraft bus	0,818597361	3,68870165	0,333795848	3,170955713		
	3. Payload malfunction due to mechanical issues	2,324675108	3,043852779	2,15761418	1,834255907		
	4. Payload malfunction due to software issues	1,525237476	1,295994771	1,013506222	2,587814909		
SC-1		2,131955459	3,226776124	2,256365596	3,380438888		
	1. No frequency on which to communicate with spacecraft due to delay in receiving frequency allocation	2,085695988	4,154047166	2,085695988	4,988458665		
	2. Failure of spacecraft radios (due to either hardware or software issues)	2,160066331	2,782126697	2,5	2,184897936		
	3. Failure of spacecraft antennas due to improper deployment or activation	1,972371867	2,462600152	1,868264145	2,083293252		
	4. Failure of ground station radios (due to either hardware or sofware issues)	2,177519859	2,270970959	2,5	2,270970959		
	5. Failure of ground station antennas						

Fig. 9. Comparison between NCBR2 old and current data.

Results and discussion:

Using obtained data from the software, actual critical points detected for NCBR1 in the software mission are:

- Schedule (SCH) – schedule ,
- Being unable to communicate with spacecraft (SC-1),
- Unable to gather data from spacecraft (SC-2),
- Loss of human knowledge and experience (PER);

As NCBR1 has been transmitting its payload data for more than a year, its scientific mission has already been complete. Therefore, the first critical point Schedule can be dismissed.

Due to recent solar activity, NCBR1 batteries are unable to recharge and keep power for a long period of time. As a result, it needs 40 minutes of solar incidence for being able to receive and transmit data. The suggestion of improvement to avoid this kind of problem in future missions is the Orbit Analysis. As NCBR1 was unable temporally to communicate with Program Ground Station because of limited solar exposure time on its orbit, this problem could be avoided in future missions with careful orbit analysis taking in account solar time exposure until reach Ground Stations and power consumption in this period. As a result, it will be able to collect data from its payloads, receive and transmit. This suggestion can be attached to SC-1 and SC-2 critical points found. The following image (Fig. 10.) shows the development phase to implement this improvement, in V-Model.

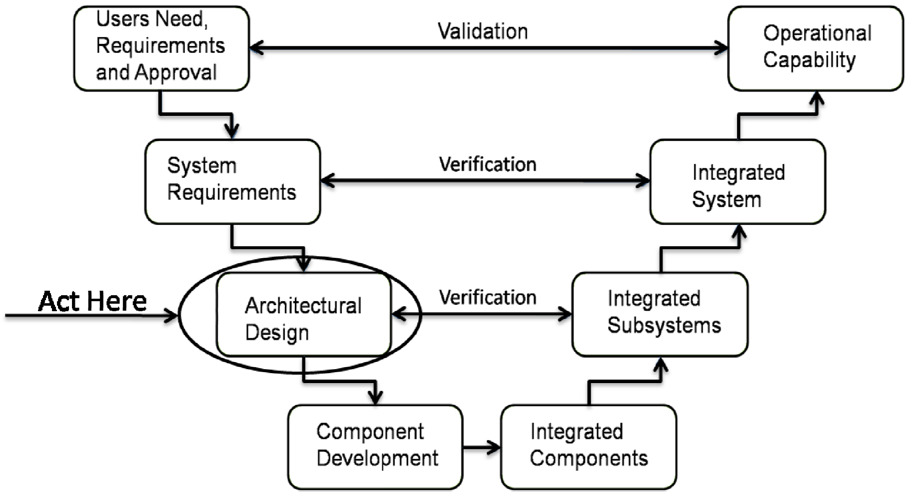
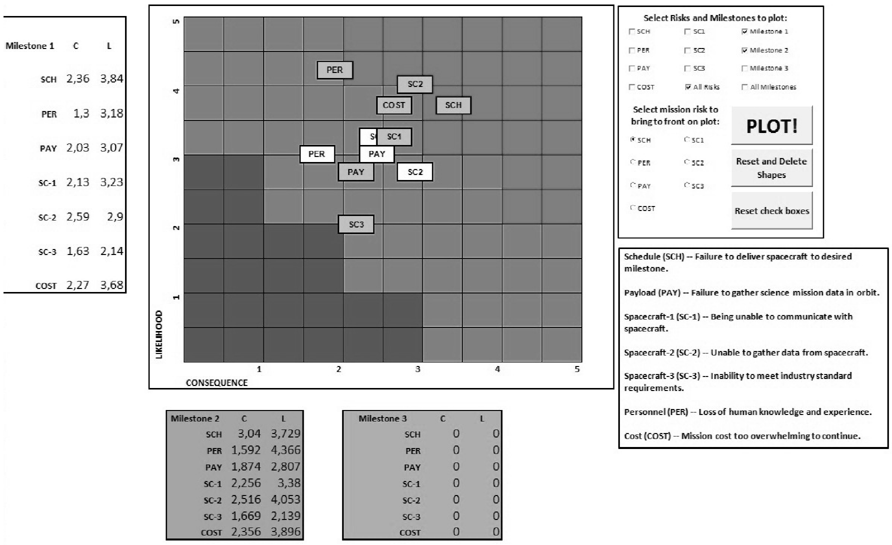


Fig. 10. Shows where act in V-Model



Finally, the loss of human knowledge and experience is a real problem, especially to university undergraduate programs due to small time of students permanence in college before graduation. In NANOSATC-BR, CubeSats Development Program it is being avoided with gradual change with new undergraduate students members, so the experience and knowledge can be shared and transferred to the new incoming students. An intern network with access to all the NCBR Program documents helps to reduce this problem. This should be applied to all parts on the V-Model to ensure the role project is covered.

Fig. 11. Shows graph comparison between old and current NCBR2 data.

The obtained critical points (Fig 11) for NANOSATC-BR2, (NCBR2), are:

- Schedule (SCH) – schedule,
- Unable to gather data from spacecraft (SC-2),
- Loss of human knowledge and experience (PER);

Critical point PER in NCBR2 can be ease with the suggestions made for NCBR1, even more both satellite being in the same Program and Team.

In output tab from the software were identified the 3 major concern points for SC-2 critical point. Two of them, with maximum likelihood, are due to inability to get/generate solar power. As suggested for NCBR1 an orbit analysis, it can be applied for NCBR2. The third point is failure of sensors getting health data. This is already minimized due the redundancy systems in the satellite.

For SCH critical point, one of the most important problems which delayed the finalization and launching of NCBR2, which was initially planned for

2013, transferred to 2014 and after postponed again for 2015, and now it is being planned for launch window for June/July 2016 by a DNEPR in a Russian Launch Base is the severe and very heavy Brazilian bureaucracy with the availability of its financial budget from the Brazilian Space Agency. However, the Program General Coordinator and Project Manager is negotiating with the Ministry of Science, Technology and Innovation - MCTI the approval of a special document "TED" in order to permit the NCBR2 Team mobility and its launch in 2016. Therefore, the problem is neither technical nor Capacity Building availability even of infrastructure, but only bureaucratic in decision taking.

Conclusions

With obtained risk data and possible improvement, it is observed that some suggestions can be applied in general nanosatellite missions generating great improvement such as SC-2 faced from both NCBR1 and NCBR2 CubeSats. PER can be mitigated in all satellites from the program (actual and future) using the proposal suggested.

Some other critical points should be analyzed for each satellite mission (scientific and technological) and current mission development phase.

Acknowledgements

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