Title: Disaster Monitoring Constellation using Nanosatellites
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Need

African and Asian developing countries need support to face natural disaster like floods, forest fires, desertification, and locust monitoring. The problems of desertification and locust are especially related to African countries which have not capacities to face it.

Mission Objectives

The main objective is to launch the first low cost disaster monitoring constellation which allows to different developing Asian and African countries the access at the satellite images to face different natural disasters.

- Floods: analysis and assessment of damage caused by floods, able to restore decision authorities with the necessary key information for emergency measures to be undertaken.
- Locust biotopes monitoring: analysis of ecological conditions in the regions of desert locust breeding.
- Forest fires: characterization of forest, prevention against forest fires, and aid for decision authorities.
- Desertification: realization of different maps of desertification sensitivity for many African countries.

The other main objective of this mission is to encourage the African developing countries to acquire the space technology to develop low cost constellation for their economic development and to obtain a multidisciplinary team which, by the end of the project, shall be able to design integrate and operate a full nanosatellite mission.

In absence of disaster, the constellation is dedicated for educative and scientific purposes.

Concept of Operations

The mission is composed of a constellation of four (04) Nanosatellites, a ground segment for commands, telemetry and monitoring and for image processing. The launcher to be selected for the constellation is PSLV which presents the advantage of its low cost regarding other launchers.

The space segment is a nanosatellite of a total mass less than 12 Kg. It is based on the ISIS 6U platform [1]. The payload is a multispectral pushbroom imager suitable for wide range of missions in LEO. It is encapsulated in a compact unit and provides 3 multispectral channels, with an effective sensor length of 2098 pixels per channel.

To support the four nanosatellite of the constellation, an existing modular ground station used for the ALSAT-1 DMC will be adapted to fit with the requirement of the mission [2]. The existing ground station support the communication in VHF/UHF/S-band. It is implemented in the Centre of space Techniques building, located in Arzew, west of Algeria. It includes a 3.7 m parabolic dish and radio for receiving and transmitting the S-band signal and Yagi-Uda antennas and radio for the bidirectional UHF communications and for receiving the VHF beacon. The ground station software will be modified and adapted to meet the mission requirements.

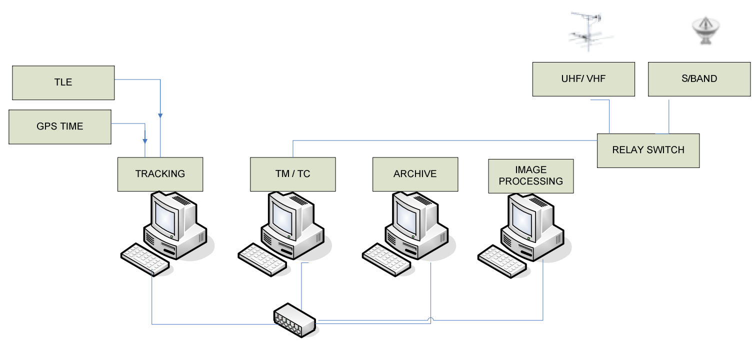


Figure 1: Ground Station Architecture Diagram

Figure 2: VHF/UHF Antenna structure

Figure 3: S-band Antenna structure

Regarding the operational concept, three operation phases are summarized below:

Before nominal operation: Launch and Early Operations Phase (LEOP) starts after satellite separation from the launcher. This phase includes the antenna deployment, initial satellite acquisition (Beacon signal), validation of the satellite-ground station link, switch ON the equipments, acquisition and transmission of the first image even the orbit is not yet corrected to validate that the satellite is not damaged during launch. After the first image, a phase of orbit correction will be performed to position each satellite in its mission orbit. The period of corrections depend on the accuracy of injection by launcher. Once the satellite is placed on its mission orbit, a commissioning phase starts. During this phase, the performances of the satellite will be tested and validated. The results will be used to correct and calibrate the on ground satellite models.

Nominal Operations: during nominal operation phase, the satellite will be fully operational and shall perform the earth observation mission in accordance with the defined timeline. This phase starts from the end of commissioning phase and up to 24 months after launch.

Contingency Operations: to avoid surprise during different phases (in particular LEOP phase) and to prepare the solutions in advance, possible failure scenarios and recovery plans will be elaborated.

Key Performance Parameters

For each nanosatellite, the camera used gives a 146km field of view at 62 meters spatial resolution in three spectral bands, the Red, Green and Near Infra-Red. This field of view allows the constellation to cover the whole earth within 72 hours and to communicate with the main ground station located in Algeria or another (so-called) auxiliary ground stations situated in other developing countries. The band spectrums selected for this mission are the Red, Green and Near Infra-Red:

- Green: [0.52 -0.60] μm
- Red: [0.22 -0.69] μm
- NIR: [0.77 -0.90] μm

The nanosatellite is three axis stabilization when imaging and evolves in a BBQ mode out of imaging time. The Attitude Determination and Control Subsystem give acceptable attitude pitch/roll/yaw stability during imaging (< 0.2 deg). The imaging system allows windowing and it is supported by a total storage capacity of 2 Gbytes. The mission is designed to record a maximum of 16 elementary images 2098x2098 pixels per day, which could be downloaded to a ground station at 1 Mbps data rate within the four visibilities per day with a total duration of about 32 min.
In order to assure circularization of the constellation satellites, the station acquisition (which allows the satellites to equally separate from each other so the daily global coverage is respected), and the station keeping of the 4 satellites, each nanosatellite of the constellation is equipped with a propulsion system with 50mN thrust and a tank with a capacity of 0.9 liters. The preliminary total delta V estimated is about 25 m/s and can reach 30 m/s.
The mission lifetime for each nanosatellite is 18 months and can reach 24 Months or more by introducing added protections against radiations (shielding on the sensitive equipments).

Space Segment Description

The satellite is equipped with camera to take images with 146km field of view and 62 meters spatial resolution in three spectral bands, the Red, Green and Near Infra-Red. It will be powered by a battery that is charged by solar arrays on the outside of the structure. A Data handling payload will process, store and send the images to the S-band transmitter for downloading to ground station. The orbit of the satellite will be controlled by a passive attitude control system and will be oriented based on the Earth's magnetic field. The structure will be designed to meet its mission objective and to meet the specifications of the interface system that will be use for launch vehicle integration.
The Nano-satellite specifications state is 15 Kg, maximum mass allocation. Since it is the preliminary design, the mass budget is based on the primary design. It will be updated in the following phases. The overall mass of the satellite is about 11.5 Kg, which means a margin of about 23.34%.
In the choice of components, tolerance to radiation had to be considered towards the harsh LEO environment. Anti-fuse radhard FPGA for Payload data handling, anti-latch-up function in the

command data handling system and experience learning from similar cubesat based mission flying with analogue chip which reveal over estimated effective mission lifespan as Libertad-1 and Delfi-C3. Also the interior arrangement of sub-systems boards had to be done according to former cubesat based missions setting OBC between the other boards. The COTS selected have tolerances up to 500krad of radiation and temperature tolerances in the range of -40 to 85 deg. C.

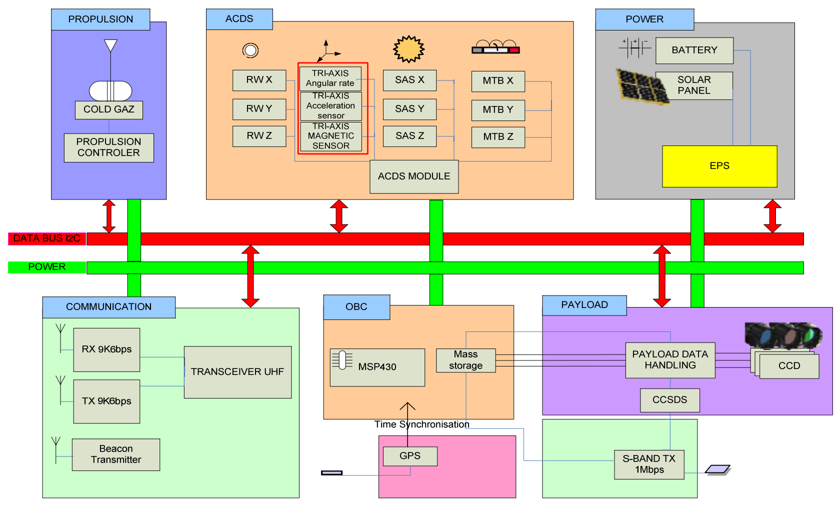


Figure 4: Nanosatellite block diagram

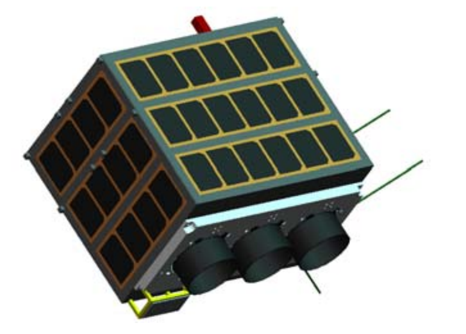


Figure 5: Outside satellite configuration

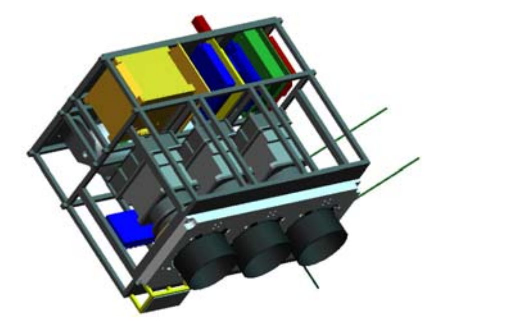


Figure 6: Preliminary satellite configuration

Payload : The objective of the mission is to take, process, store, and transfer during one visibility up to 3 or 4 elementary images of 2098x2098 pixels image (15,75 Mbytes). To achieve this, we have selected a line scan camera system designed to provide medium resolution of 62m, high dynamic range and low noise imagery. The image sensor selected is KODAK KLI-2113 with an imager size of 29.37 mm x 0.24 mm, which offers high sensitivity, high data rate and low noise. For each sensor, only one line among three is drived to obtain one active CCD line for each multispectral band.

To meet the mission requirements (low cost and time development), the sensor element will be requested without the RGB organic dye filters. A specific filter is procured from BARR to achieve the required spectral bands. The lens is a Schneider Apo-Componon. It's a flight proven lens (flown onboard Tsinghua-1 and Alsat-1). This commercial lens has been subject to a set of test prior to use.The camera board consist in three video chain composed for each of a pre-amplifier for CCD signal and a correlated double sampling and 10 bit A/D converter function represented in Analog device 9840A chip. Meanwhile a high density FPGA is used to interface via the used bus between the video chain, the mass memory hosted by the on-board data handling FM430 and the TX sub system. A dedicated Actel FPGA RT54SX is used to packetize the mission data in CCSDS format before transmission.

Attitude Control system: The main goal of the attitude determination and control system (ADCS) is guarantee an accurate earth pointing when imaging. This can be achieved using sensors for acquiring spacecraft attitude and position, and after performing on-board calculation or receiving ground commands the spacecraft makes use of actuators to achieve the desired attitude or trajectories. Once the spacecraft achieves a certain desired attitude or orbit the role of the ADCS is not over because of the continuous disturbing forces acting on the spacecraft: aerodynamic drag, solar radiation pressure, gravity gradient torques and genetic field torques.

The proposed ADCS is based on the ADACS IMI200 integrated system from Maryland Aerospace, Inc, that uses 3 axis active controls with 3 reaction wheels and 3 magnetorquers providing 0.02Nms momentum and 5mNm as maximum torque. In addition, 3 sun sensors, triaxial gyroscope, triaxial accelerometer, and triaxial magnetometer to enhance the attitude determination for an accuracy of about 0.2°. The miniaturized sun sensors are provided from SFL/Sinclair interplanetary Company, and the triaxial inertial sensor with analog magnetometer is from ANALOG DEVICES, Inc. A fixed nadir pointing is set as nominal pointing, even for imaging mission or in eclipse, since the payload is a multispectral camera. The ADCS works with three modes, the detumbling mode applied after launch separation using magnetorquers, the imaging mode with nadir pointing, and barbeque mode (BBQ) for thermal equilibrium, in this mode the satellite is spinning around the yaw axis which is pointing toward earth. The imaging and the BBQ modes are achieved by the reaction wheels and magnetorquers for momentum dumping. However, when proceeding to orbital maneuver, the satellite cans slew to some degrees to perform the required maneuver.

The GPS receiver selected is the SGR-05U from SSTL, used for an accurate timing and synchronization.

Electrical and Power Systems: The preliminary satellite power (an average of 15 to 22 W depending on orientation and orbit) is provided by 58 GaAs junction, placed on the four lateral sides of the structure and a Lithium Polymer battery (CS-SBAT2-30) with a capacity of 30 W.h and a depth of discharge of 20%. In order to improve the total power provided by solar arrays and the thermal protection of the satellite, the solar arrays will be specified in accordance with the exact dimensions of each lateral panel. The battery is required for the mission because the solar cells alone can not produce enough power when peak power is needed and provides power to subsystems that can not be turned off while the satellite is in eclipse. The power and electrical subsystem has to accommodate a variety of power needs as required by the mission timeline. If the satellite is in sunlight and takes and transmit images to ground station, the payload and both transmitters (UHF and S-band transmitter) will all need full power to operate. In these conditions, the satellite acquires supplementary power from the battery.

Regarding the calculated peak power (all equipments ON) shown in Table 1, it is recommended that no mission (neither imaging nor data read) will be performed the day of orbital maneuvers because 10 W is required for the heater and the pipe heater to evaporate the liquid butane before injection through the thruster.

Equipment	Peak power (W)	Power (Imaging mode) (W)	Power (orbital manoeuvre) (W)	Power (BBQ mode) (W)	Power (Imaging + Read mode) (W)	Power (Read mode) (W) During Night visibilities
ADCS	4.925	4.925	4.925	4.925	4.925	4.925
Payload (imager + electronic parts)	7	7	OFF	OFF	7	OFF
Command & Data Handling	0.22	0.22	0.22	0.22	0.22	0.22
S-band Transmitter	5	OFF	OFF	OFF	5	5
VHF Beacon Transmitter	1.5	1.5	1.5	1.5	1.5	1.5
Transceiver UHF TM/TC Data	2.71	2.71	0.000066	2.71	2.71	2.71
GPS receiver	1	1	1	1	1	1
Propulsion System	10	OFF	10	OFF	OFF	OFF
Electrical power system	0.1	0.1	0.1	0.1	0.1	0.1
Total Power (W)	**32.455**	**17.455**	**17.745**	**10.455**	**22.455**	**15.455**

Table 1: Nanosatellite power budget estimation

Communications: The communication to and from the satellite (control, command, and monitoring) is achieved using a commercial UHF transceiver (NanoCom U480) operating in the amateur radio band. The images data will be transmitted by using an S-band transmitter operating in the commercial band (2.2 -2.29 GHz), with a data rate of 1Mbps and an output power of 1 W. Also, a dedicated transmitter operating in VHF band will be used to send a beacon signal containing satellite health to aid in satellite identification, tracking and monitoring, particularly in the days following launch. Monopole and patch antennas are used for uplink and downlink communications. The uplink and the downlink budgets show very good margins. Table 2 illustrates the S-band Telemetry link budget.

S-BAND TELEMETRY LINK BUDGET						**V1.0 of the 07/12/10**
Frequency	2260,00 MHz	***Link data***		***Station***		
Polarisation	C	Orbit Altitude	680 Km	Name	ARZEW	
		Availability %	99,00	Latitude	35,8585000 °	
Data rate - to download images data	1,00 Mbps			Longitude	-0,3139000 °	
Modulation	QPSK			Height	0,260 Km	
Coding	Conv. (R=1/2)			Antenna Diameter	3,7 m	
				Antenna Gain	25,8 dbi	

		Nominal Mode				Comments
SL to G/S site angle		5 °	10 °	45 °	89 °	
SL - Station distance		2517 Km	2112 Km	919 Km	680 Km	
On-Board field of view		64,19 °	62,86 °	39,72 °	0,90 °	
Transmitter output power	dBW	1,00	1,00	1,00	1,00	
Pertes harnais	dB	-1,00	-1,00	-1,00	-1,00	
On-board antenna gain	dBi	4,00	4,00	4,00	4,00	
S/C EIRP	**dBW**	**4,00**	**4,00**	**4,00**	**4,00**	
Space losses	dB	-139,01	-137,48	-130,26	-127,64	
Gaz losses	dB	0,41	0,20	0,05	0,04	
Scintillation losses	dB	0,82	0,36	0,07	0,04	
Cloud losses	dB	0,02	0,01	0,00	0,01	
Rain losses	dB	0,00	0,00	0,00	0,00	
Total atmospheric losses	dB	-1,23	-0,56	-0,12	-0,08	
Flux density at G/S	**dBW/m2**	**-136,24**	**-134,05**	**-126,38**	**-123,72**	
Isotropic area	dBm2	-28,54	-28,54	-28,54	-28,54	
Ground station G/T	dB/K	11,10	11,40	11,90	11,90	
Pointing losses	dB	-0,50	-0,50	-0,50	-0,50	
Polarisation losses	dB	-1,00	-1,00	-1,00	-1,00	
G/T degradation due to rain	dB	-0,18	-0,09	-0,03	-0,02	
Received C/N0	dBHz	73,25	75,82	84,06	86,73	
Rx + Tx quality losses	dB	-2,00	-2,00	-2,00	-2,00	
Useful data rate	Mbps	1,00	1,00	1,00	1,00	
Eb/N0	**dB**	**11,25**	**13,82**	**22,06**	**24,73**	
Required Eb/N0	dB	6,35	6,35	6,35	6,35	
Margin	**dB**	**4,90**	**7,47**	**15,71**	**18,38**	

Table 2: S-band Telemetry link budget

Computer: the OBC used in the design consists on a single board computer flight module FM430 designed by Pumpkin for low cost low power consumption embedded applications build around a Texas Instrument 16-bit TI MSP 430 microcontroller made for harsh environment. This choice offers an operational reliability (Libertad-1, Delfi-C3). The flight Module computer is charged to monitor satellite and payload housekeeping parameter, manage bidirectional communications with the mission's ground station, handling data storage and retrieval as well satellite control. The OBC is the master of the I2C-bus on the satellite and the other sub-systems are slaves.

Software: Salvo Pro RTOS is used to handle all software tasks. Highly configurable and low cost Pumpkin product it can run multiple prioritized tasks and works with a cooperative scheduler. Ideally suitable for MSP430's 2K RAM and allows application to sleep at all times, waking only for activity when specified events occurs. Well documented it can be developed under Non-intrusive environment and easy to debug. The mission specifications will be developed under Salvo Pro RTOS environment.

Structure: The proposed structure of the Nanosatellite must hold all the components and fit the specifications of launch vehicles. The structure is made of Aluminum and based on two main parts, the platform structure which is U6 Cubesat platform to hold the components and payload structure for the camera. Four lateral panels attached to the structure to support the solar cells, the camera is placed on the bottom panel for pointing to the earth. The satellite envelope is 340 x 360 x 280 mm3, and the satellite total mass will be less than 12 kg. For the reason of the satellite envelope the POD-types separation systems cannot be used. For our mission AxelShooter separation system is selected, which ensures protrusions such as antennas and camera and allow the visual inspection and operation check after attachment [3].

Thermal: A passive thermal protection system consisting of proper insulation will be used to provide proper protection from radiation and heat fluxes. This insulation will consist of a layer of Kapton outside the panels, which will also act as an adhesive for the solar panels, and MLI inside the structure. Since solar panels will be covering most of the panels, the layer will be acting as additional insulation. Additional thermal covering will be used around the most thermally sensitive components.

Propulsion: A butane cold gas propulsion system utilising 460 grams of propellants to meet the mission requirements (delta V of about 25 m/s and can reach 30 m/s) will be developed. One tank will be used with 0.9 litres capacity for the storage of butane at maximum pressure of 4 bars. The tank will be connected to the thrusters using pipe heater to evaporate the liquid butane before injection through the thruster [4]. The propulsion system delivers approximately 50 mN thrust.

Orbit/Constellation Description

Since many Nanosatellites are typically launched as a secondary payload, its precise orbital trajectory is dictated by the requirements of the primary mission. Based on previous cubesat launch trends, a sun-synchronous reference orbit has been chosen with an inclination of 98.08 degrees, an altitude of 670 km over equator, and a period of 98.25 mn. The local solar time used in the design is 10h +/-30 mn and will be adjusted when the launch opportunity is defined. This orbit allows to obtain an image swath of 146km, which allows to the four satellites of the constellation to cover the whole earth within 72 hours. It also allows to the ground station to communicate with the satellites four times per day with an average duration of 8 min per visibility. The minimum elevation considered for VHF/UHF/S-Band communications is 5 deg.

This reference orbit is a design guide constructed from historical averages, and additional worst-case figures must be considered whenever possible throughout the mission design process. In order to have different earth coverage by each satellite and to avoid simultaneous visibility of two nanosatellites or more from the principal ground station, the reference mission orbit of each satellite, and especially the argument of latitude will be carefully defined. The description of the position of the nanosatellites constellation is done by the following Figure 7.

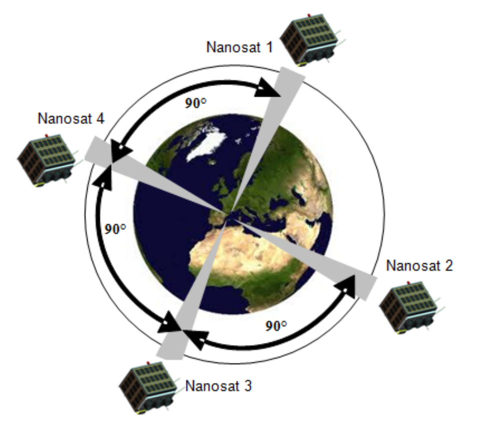


Figure 7: Nanosatellite constellation phasing

Implementation Plan

The Centre of Space Techniques is the technical entity, working with the Algerian Space Agency on the conception, realization and operations of different satellite missions (earth observation, communication). To date, two earth observation microsatellites have been successfully launched (ALSAT-1 and ALSAT-2A) and a third satellite ALSAT-2B is planned for launch in the two next years. The two first satellites have been realized with a cooperation with SSTL for ALSAT-1 and EADS-Astrium for ALSAT-2A.

For this mission, the conception, realization, integration, and tests of at least one Nanosatellite of the constellation will be performed in the Satellite Development Centre CDS facilities. The CDS is a new centre located in Oran city (Algeria), which will be inaugured in Mid of 2011. It contains a clean room, vacuum, acoustics, vibration and RF facilities to perform environment tests. Figure 8 shows the project organization.

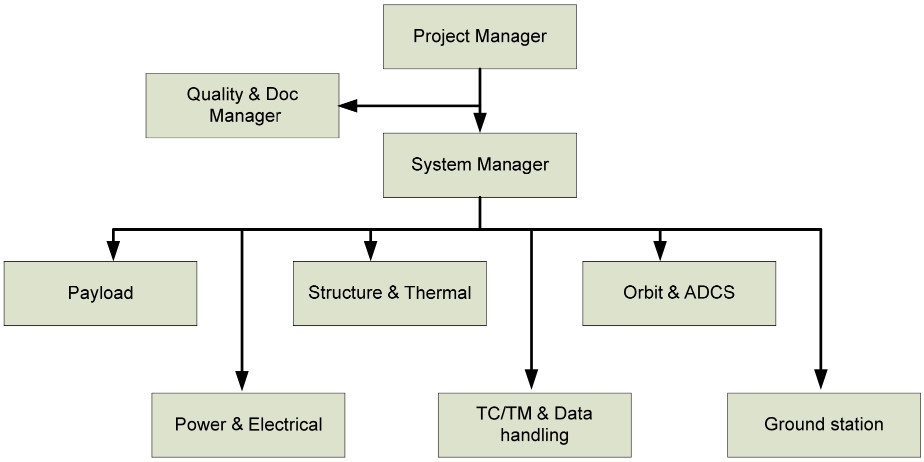
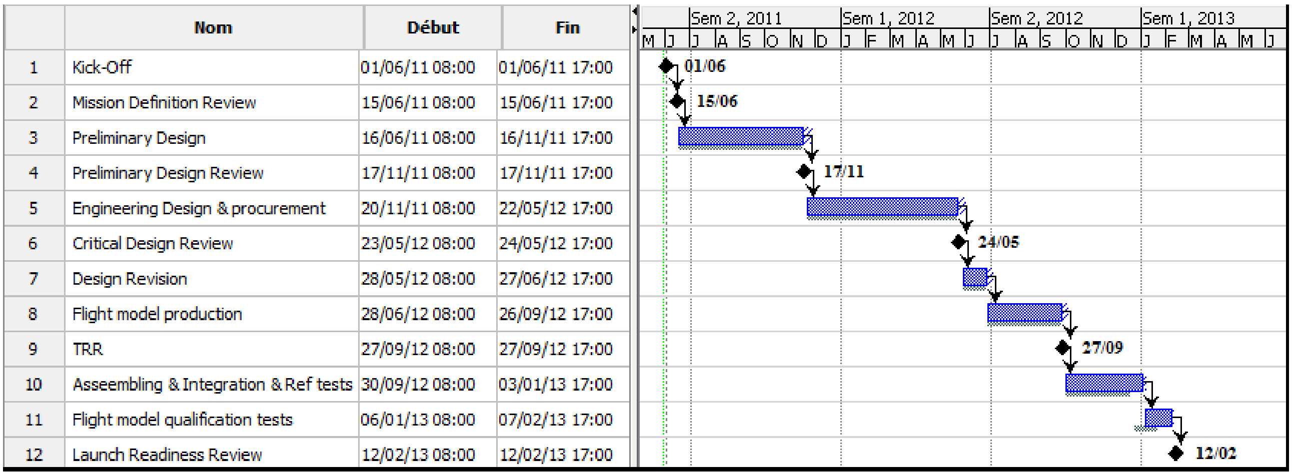


Figure 8: Organizational structure of the project

The schedule of the different phases of the project (design, development, assembly, integration, testing, and qualification) is shown by Figure 9. The final launch and operations phase will begin 6 weeks before the launch window.



	Nom	Début	Fin
1	Kick-Off	01/06/11 08:00	01/06/11 17:00
2	Mission Definition Review	15/06/11 08:00	15/06/11 17:00
3	Preliminary Design	16/06/11 08:00	16/11/11 17:00
4	Preliminary Design Review	17/11/11 08:00	17/11/11 17:00
5	Engineering Design & procurement	20/11/11 08:00	22/05/12 17:00
6	Critical Design Review	23/05/12 08:00	24/05/12 17:00
7	Design Revision	28/05/12 08:00	27/06/12 17:00
8	Flight model production	28/06/12 08:00	26/09/12 17:00
9	TRR	27/09/12 08:00	27/09/12 17:00
10	Asseembling & Integration & Ref tests	30/09/12 08:00	03/01/13 17:00
11	Flight model qualification tests	06/01/13 08:00	07/02/13 17:00
12	Launch Readiness Review	12/02/13 08:00	12/02/13 17:00

Figure 9: Gantt chart for the Nanosatellites constellation schedule

The total estimated budget for 4 Nanosatellites is $1,831,296.00. The projected cost budget is provided below in Table 3. The launch cost is not included in the cost budget.

	Cost ($)	Cost ($)
	1 Nanosatellite	4 Nanosatellites
Flight model, including tests facilities costs	407,824.00	1,631,296.00
Human @ 20 months		200,000.00
Total		1,831,296.00

Bellow, the top 5 project risks are listed:

- Financial support for realization
- ITAR license on some equipments
- Delay on the inauguration of the CDS centre
- No opportunities of Launch defined to date to precise the mechanical levels for qualification
- Personal and test facilities required for testing the performance of the camera (ex: Collimation test), which need to be performed by experts

References

[1] CubeSat Kit Home. (n.d.). Retrieved from CubeSat Kit: http://www.cubesatkit.com

[2] ALSAT-1 documentation

[3] Nano-Satellite Separation Mechanism AxelShooter, http://www.axelspace.com/product/AxelShooter_e.pdf

[4] D.Gibbon, Dr C.Underwood, Prof M.Sweeting, R.Amri "Cost effective propulsion systems for small satellites using butane propellant" 52nd International Astronautical Congress 1-5 Oct 2001 Toulouse, France.