Title: Laser-Assisted Rain Control Constellation (LARC-CON)
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Need

Every year, thousands of lives and national economies are lost in natural disasters caused by unbalanced rainfall: floods, heavy storms, droughts. Many efforts have been made in water management (dams, flood ways) but when it comes to rain controlling, only few techniques exist. Moreover, the efficiency of such techniques is limited in local areas and they usually imply use of dangerous chemicals. The ability to reduce and induce rainfall with high accuracy and efficiency in a desired area and during a specific period of time will be a great benefit for mankind. Moreover, the new rain controlling scheme should not use toxic chemicals in order to respect the environment.

Mission Objectives

1. Induce rainfall over the dry areas when the LARC-Beamers are passing over the area
2. Induce rainfall from rain clouds over the oceans or the seas in order to prevent heavy rain from falling in flood-prone areas.
3. Provide near real-time localized meteorological data
4. Improve current meteorological prediction with more accurate and up-to-date data.

Concept of Operations

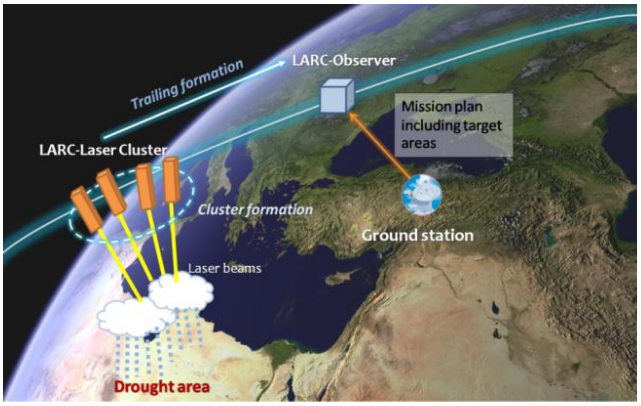


Figure 1: LARC-CON Space Segment

The meteorological data that the system will need to predict cloud localization come from two sources: available data from meteorological satellites and from a newly launched LEO EOS called LARC-Observer. The existing data might come from some GEO and Polar orbiting satellites such as TRMM, NOAA (AMSU instrument) and the upcoming NASA/JAXA GPM mission due for launch in 2014/2015. The information will be analyzed and sent from the ground station together with a mission plan including sensitive areas that rain controlling should be operated. Besides, LARC-Observer will combine this received data with the near real-time cloud formation information obtained from its on-board infrared spectrometer. With this technique, we can pinpoint the location of rain bearing clouds with high precision and confirm this information just before the rain inducing operation.

Once the target cloud is localized and confirmed, LARC-Observer will send a command to its trailing cluster of LARC-Beamers which are nano-satellites with an on-board laser emitter. When the beamers reach over the target cloud, they will orient themselves to the target cloud and fire laser beams with enough energy to split N2 and O2 in order to form rain inducing NO particles. This is inspired by the new research [1] on rain inducing technique based on Terawatt-Femtosecond 800nm laser. The LARC-Beamers are always in communication with the LARC-Observer and sends its location and orientation update. The LARC-Beamer then sends time tracked commands with the orientation and rotation commands to each individual LARC-Beamer before each laser firing operation.

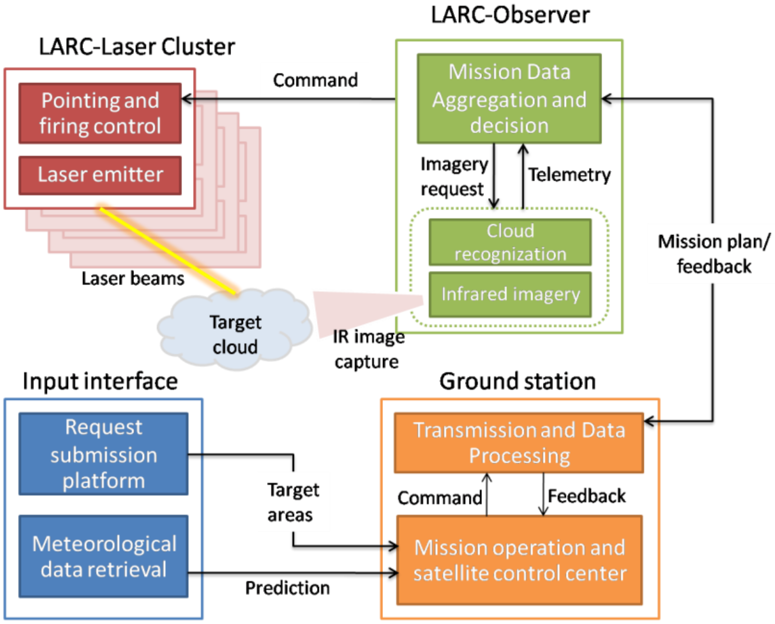


Figure 2: Architecture of the LARC-CON system

Key Performance Parameter

A major critical item is the conversion and uprating of a terawatt-femtosecond Ti:Sapphire pulse laser system as used in [1] for use in orbit. The power requirement of such laser system is enormous. Therefore, in order to cope with such high power requirements, we opt to use several Beamers pointing at the same target in order to concentrate the energy. The power requirements for on-board laser must be optimized and have to be provided by the satellite solar array over the orbit period with onboard storage in capacitance in order to provide the high power during laser usage. The use of ultra capacitor for high-speed charging and discharging of the battery is a critical factor for the success of the mission.

The pointing of the laser from the satellite to the cloud is a very important factor. Precise position and orientation information from GPS receivers and inertial sensors on-board the LARC-Beamers are transmitted periodically to the LARC-Observer. Based on this information, the Observer must be able to calculate and propagate the positioning and orientation data back to each Beamer. the attitude is incorrect by a small figure ~ 0.01 degree, the four Beamers will not be able to superimpose and power received at the cloud may not be enough to initiate condensation. Therefore, the ADCS accuracy is a key performance parameter.

Lifetime of the satellites will be dependent on the orbit height selected – however the effectiveness of the laser will also be a function of the distance so there is a tradeoff between orbit height (duration) and laser power requirement – if the laser needs to be within 100 Km of the cloud than the orbit will be low so that drag effects will be evident (below 200Km) [3] and the lifetime of the satellites will be reduced to a few months. However, in order to ensure that the mission continues, dead LARC-Beamers may be replaced with new LARC-Beamers to maintain the constellation. However, the lifetime of the project can be considered infinite as the satellites can be replaced when needed by launching new satellites to join the constellation.

Space Segment Description

The space segment consists of two types of satellites – LARC-Observer and LARC-Beamer. The defined objective of each satellite is provided below:

1. LARC-Observer:
   a. Receive telemetry from LARC-Beamers : satellite position and orientation
   b. Measure cloud coverage with infrared imagery when flying over the area of interest
   c. Identify target clouds using its location and orientation and process the target cloud localization
   d. Process cloud localization data with LARC-Beamers position to generate laser firing instructions for each LARC-Beamer
   e. Send separate commands to each LARC-Beamer with identifier.
   f. Communication to ground station: reporting satellite and mission status, receiving ground command.

2. LARC-Beamers are group of satellites equipped with laser emitter:
   a. Receive and acknowledge laser firing commands from and to the LARC-Observer
   b. Provide its own positioning and orientation data collected from GPS, star trackers, sun sensors and the inertial reference unit to the LARC-Observer
   c. Change its orientation and position using 3-axis reaction wheels and plasma thrusters according to the command received from the LARC-Observer
   d. Fire the laser at the specific time and duration as per the command from the LARC-Observer

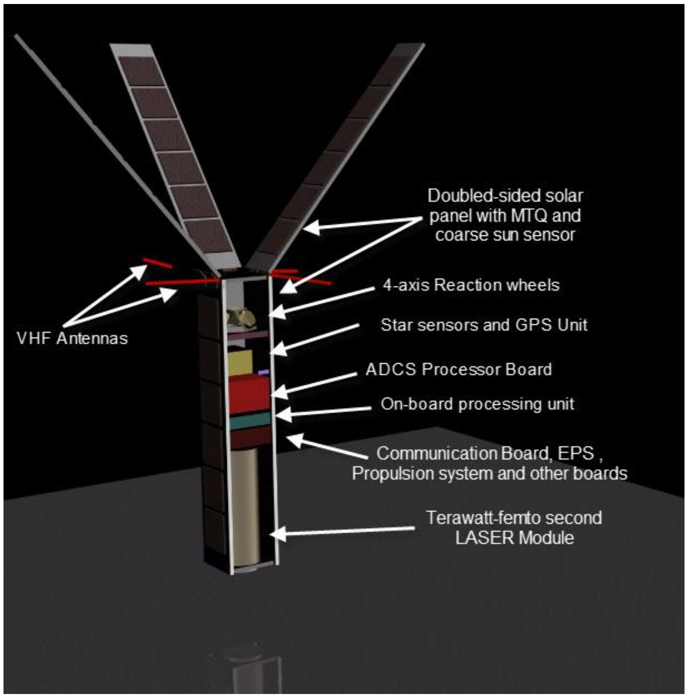
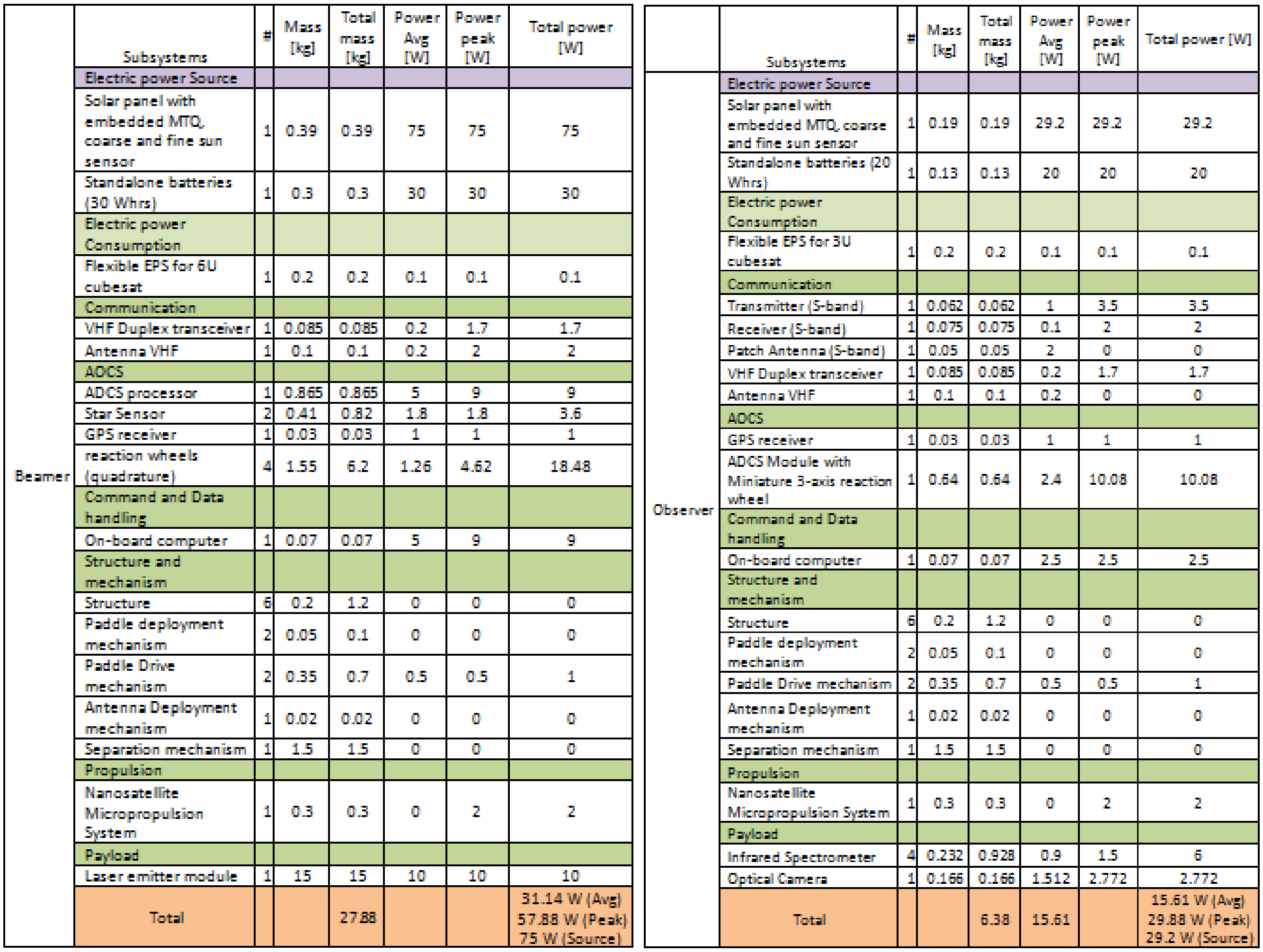


Figure 3: CAD Model of LARC-Beamer

The LARC-Observer is a 3U standard cubesat platform with 4 Infrared cameras and 1 optical imager as payload. The full platform is available off the shelf and can be procured within 8 weeks lead time. As for the LARC-Beamer, it employs the 6U cubesat structure and standard components available off-the-shelf from different cubesat manufacturers. The details of the LARC-Beamer are provided in the CAD drawing. The rationale for using off-the-shelf component is that the lead time for manufacturing is less and the equipments are space qualified. Manufacturing in Thailand can be initiated in parallel so that replacement satellites can be launched when needed as soon as needed. Both the satellites employ the AxelShooter, the separation system for nano-satellites which is compatible with ISRO's PSLV launchers [2]. All satellite launches will be done with ISRO's PSLV as piggyback satellites and the MoU between Thailand's and India's Ministry of Science and Technology can be activated to assist the launch support cost.

Keeping the specification of the requirements as well as the limitations of the size, mass and power requirement of the LARC-CON, the table below defines the specifications of both the LARC-Beamer and the LARC-Observer, providing information on the mass and power requirement of each components and the total.

Table 1: Mass and Power specifications of the LARC-Beamer and LARC-Observer



	Subsystems	#	Mass [kg]	Total mass [kg]	Power Avg [W]	Power peak [W]	Total power [W]
Beamer	Electric power Source						
	Solar panel with embedded MTQ, coarse and fine sun sensor	1	0.39	0.39	75	75	75
	Standalone batteries (30 Whrs)	1	0.3	0.3	30	30	30
	Electric power Consumption						
	Flexible EPS for 6U cubesat	1	0.2	0.2	0.1	0.1	0.1
	Communication						
	VHF Duplex transceiver	1	0.085	0.085	0.2	1.7	1.7
	Antenna VHF	1	0.1	0.1	0.2	2	2
	AOCS						
	ADCS processor	1	0.865	0.865	5	9	9
	Star Sensor	2	0.41	0.82	1.8	1.8	3.6
	GPS receiver	1	0.03	0.03	1	1	1
	reaction wheels (quadrature)	4	1.55	6.2	1.26	4.62	18.48
	Command and Data handling						
	On-board computer	1	0.07	0.07	5	9	9
	Structure and mechanism						
	Structure	6	0.2	1.2	0	0	0
	Paddle deployment mechanism	2	0.05	0.1	0	0	0
	Paddle Drive mechanism	2	0.35	0.7	0.5	0.5	1
	Antenna Deployment mechanism	1	0.02	0.02	0	0	0
	Separation mechanism	1	1.5	1.5	0	0	0
	Propulsion						
	Nanosatellite Micropropulsion System	1	0.3	0.3	0	2	2
	Payload						
	Laser emitter module	1	15	15	10	10	10
	Total			27.88			31.14 W (Avg) 57.88 W (Peak) 75 W (Source)

	Subsystems	#	Mass [kg]	Total mass [kg]	Power Avg [W]	Power peak [W]	Total power [W]
Observer	Electric power Source						
	Solar panel with embedded MTQ, coarse and fine sun sensor	1	0.19	0.19	29.2	29.2	29.2
	Standalone batteries (20 Whrs)	1	0.13	0.13	20	20	20
	Electric power Consumption						
	Flexible EPS for 3U cubesat	1	0.2	0.2	0.1	0.1	0.1
	Communication						
	Transmitter (S-band)	1	0.062	0.062	1	3.5	3.5
	Receiver (S-band)	1	0.075	0.075	0.1	2	2
	Patch Antenna (S-band)	1	0.05	0.05	2	0	0
	VHF Duplex transceiver	1	0.085	0.085	0.2	1.7	1.7
	Antenna VHF	1	0.1	0.1	0.2	0	0
	AOCS						
	GPS receiver	1	0.03	0.03	1	1	1
	ADCS Module with Miniature 3-axis reaction wheel	1	0.64	0.64	2.4	10.08	10.08
	Command and Data handling						
	On-board computer	1	0.07	0.07	2.5	2.5	2.5
	Structure and mechanism						
	Structure	6	0.2	1.2	0	0	0
	Paddle deployment mechanism	2	0.05	0.1	0	0	0
	Paddle Drive mechanism	2	0.35	0.7	0.5	0.5	1
	Antenna Deployment mechanism	1	0.02	0.02	0	0	0
	Separation mechanism	1	1.5	1.5	0	0	0
	Propulsion						
	Nanosatellite Micropropulsion System	1	0.3	0.3	0	2	2
	Payload						
	Infrared Spectrometer	4	0.232	0.928	0.9	1.5	6
	Optical Camera	1	0.166	0.166	1.512	2.772	2.772
	Total			6.38	15.61		15.61 W (Avg) 29.88 W (Peak) 29.2 W (Source)

Orbit/Constellation Description

As the satellite is small, the available cross section for solar panel is only possible for power productions up to 75 W in full deployed state. Therefore, in order to ensure that the satellite is able to provide enough energy to the laser, the altitude is kept as small as possible with the selected altitude being 250 km. The defined orbit has an inclination of 35' in order to provide near equatorial coverage over tropical countries in which rain-related natural disasters are frequent such as southern China, Thailand, Indonesia, Costa Rica, Columbia and Peru. The space segment comprises of a constellation of 30 satellites divided into 6 clusters in one plane at 35" inclination. Each cluster includes one LARC-observer satellite and 4 LARC-Beamers satellite in the same near-equatorial circular orbit at 250 km altitude. The LARC-Observer satellite leads the group of LARC-Beamers satellites by approximately 3500 km or an argument of perigee of 36 degree. This separation is to ensure that the LARC-Observer has enough time to process the cloud data and meteorological information and send the LASER firing commands to the LARC-Beamers. Keeping this orbit, the LARC-Observer has a 6 minutes lead to complete the image processing, meteorological data processing and position calculation of each LARC-Beamer before transmitting the firing command. Each LARC-Beamer are separated from the others by a small distance not more than 50m and it maintains its relative position using the commands from the LARC-Observer who has the position and orientation information of all the LARC-Beamers in its cluster.

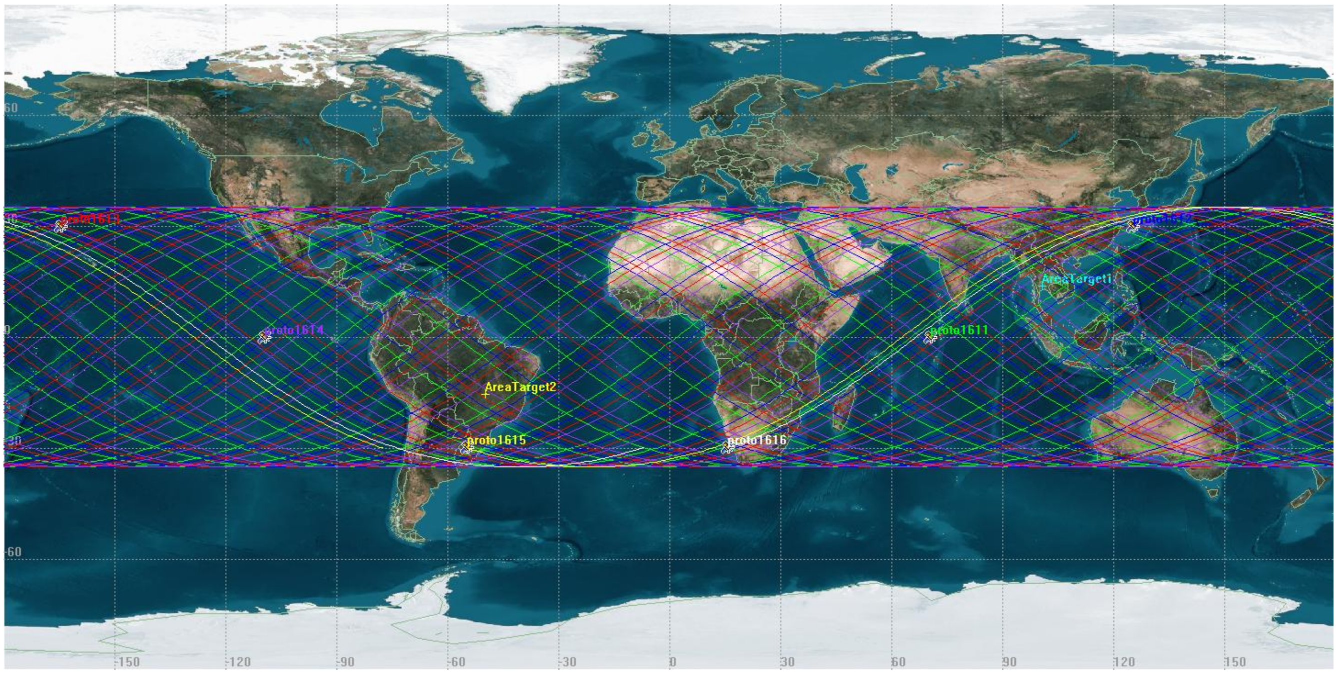


Figure 4: One-day Ground Track of the six clusters of the LARC-CON

The constellation of the satellites has 35 revisits over the 10x10 km^2 in Bangkok, Thailand with an average access period of 388.19 seconds and 35 revisits over Brazil with an average access period of 377.18 seconds. By employing just these two existing ground stations with existing antenna facility, the total passes shall be 70 which will be enough for choosing targets and commanding. Rainfall inducing lead time must be less than about the maximum life cycle of rain clouds (50 to 180 minutes) and during this time; the number of revisits over the target area must be great enough to increase the chance of making rain fall. Hence, the orbit chosen fulfills the requirement.

Implementation Plan

GISTDA would take the lead role in implementing the idea with financial support from Thailand's important natural resource management agencies such as the Bureau of Royal Rainmaking and Agricultural Aviation, Strategic Committee for Reconstruction and Future Development (SCRFD) and Strategic Committee for Water Resources Management (SCWRM). The economy damage from 2011 Thailand flood is estimated at 1,425 billion baht (US$ 45.7 Bn) and if the LARC-CON can reduce this loss by a mere 0.1 %, then there is already over 100% return on investment. Taking in consideration the estimated total cost of the Constellation with 6 LARC-Observer and 24 LARC-Beamers, the total estimated cost stands around 20 million USD which is less than 0.05% of the economy damage to the Thai economy by the 2011 Thailand flood. Considering that natural disasters of such scale occurs more than ten times a year, the LARC-CON can pay for itself over and over again and helping people at the same time. This project can also be achieved within the ASEAN or global context with support from other countries in the equatorial region facing rain-induced disasters. Some ASEAN countries with advanced capability in space technology such as Indonesia, Malaysia and Singapore could contribute with their technical support alongside with more space developed countries such as Brazil and India. Most of the countries mentioned already possess satellite ground station and these ground stations can be used to command the LARC-CON. The project will be financed by the Thai government as part of the Flood Prevention and Recovery program which has allotted billions of Baht for tools to prevent and reduce floods. Private entities such as hotel operators and city councils may also be interested in financing the program, given that they can increase tourist in the low season which is marred by persistent

Table 2: Cost Estimates

Costing ($K)	Observer	Beamer (x4)
Design Cost	80	120
Bus procurement	100	80
Payload Procurement	150	180
AIT (inc MGSE, EGSE)	50	30
Launch	200	200
Ground Segment (inc .antenna)	150	50
Operational costs	15	10
Disposal costs	5	5
Total	750	675x4
Margin	50	75

rainfall. The full implementation from Kick-off to launch will less than 24 months and the plan is provided.

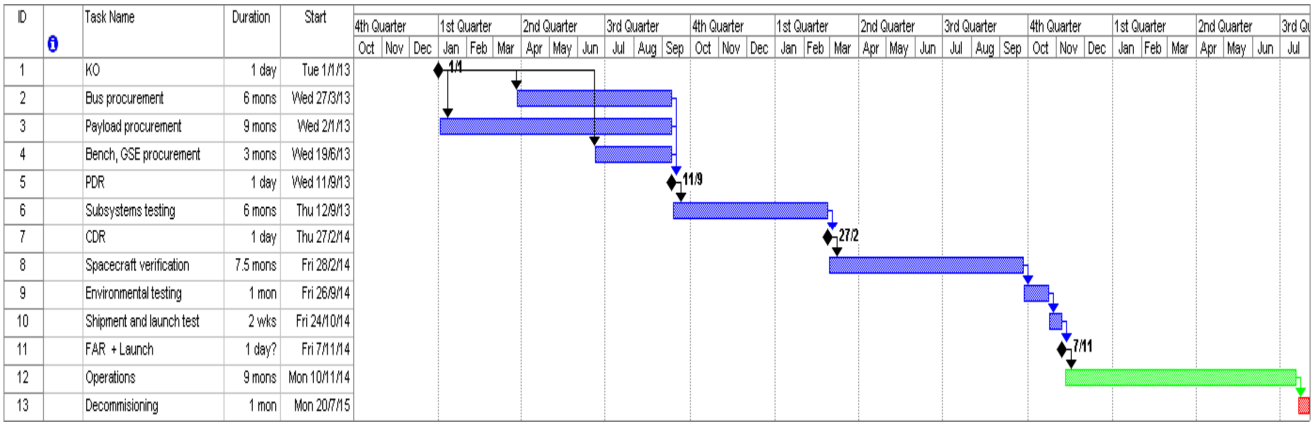
The project implementation plan will follow the classical phase system, with (Phases A-F) and a preliminary design review and critical design review prior to the commencement of the phase s C and D. It is not expected to construct a full Engineering Model of the LARC-Observer and LARC-Beamer satellites but to use test benches for verification of flight equivalent units. An AOCS test bench will ensure that the algorithms for the position calculation critical for the LARC-Beamer are verified prior to embedding in the OBSW.

The spacecraft bus procurement is expected to take a little over 6 months using a standard nanosat design (such as the SSTL SNAP), the payload will be procured over 6-12 months with concentration in the Phase-B on the beamer technology which will require a specific laser test bench for calibration and instrument accuracy, including dissipation.

During Phase C the buildup of the ground segment, including the image processing segment will have a similar phased design, and the PDR will concentrate on the image processing turnaround for the LARC-Observer data and feedback loop to the LARC-Beamer command and control. Only the LARC-Observer and one of the LARC-Beamer satellites will go through environmental testing. The ground segment will be based on a GISTDA development, and additional costs will be for the tracking antenna system. All satellites of a cluster will be launched on a single launcher, such as PSLV, and may be piggy-backed with other satellites to reduce costing. Due to the low orbit characteristics the satellites will be de-orbited towards the end of lifetime in a controlled disposal.

The table gives estimated costing, based on a ClydeSpace/SSTL/Pathfinder type bus procurement, with integration and testing performed locally in Thailand within a student training program sponsored by GISTDA.

Project schedule:



ID		Task Name	Duration	Start
1		KO	1 day	Tue 1/1/13
2		Bus procurement	6 mons	Wed 27/3/13
3		Payload procurement	9 mons	Wed 2/1/13
4		Bench, GSE procurement	3 mons	Wed 19/6/13
5		PDR	1 day	Wed 11/9/13
6		Subsystems testing	6 mons	Thu 12/9/13
7		CDR	1 day	Thu 27/2/14
8		Spacecraft verification	7.5 mons	Fri 28/2/14
9		Environmental testing	1 mon	Fri 26/9/14
10		Shipment and launch test	2 wks	Fri 24/10/14
11		FAR + Launch	1 day?	Fri 7/11/14
12		Operations	9 mons	Mon 10/11/14
13		Decommisioning	1 mon	Mon 20/7/15

Risks:

1. Lack of financial support due to immaturity of the laser-assisted rain control technology. However, the flight itself can also function as a proof of concept and technology demonstration for laser technology in space. Further research in this domain might endow investors' confidence.
2. The punctual and extremely high power demand of beamers might result in the inability to procure adequate off-the-shelf power distribution module for the laser emitter payload. Implementation of such module for scratch might result in extensive project delay.
3. Unexpectedly elevated renewal rate of Beamers might result in exceeding anticipated project cost.
4. The laser might damage or interfere with some aircraft system. The influence of the laser must be thoroughly studied and anticipated with air traffic control authorities.
5. If the global warming situation worsens, there would be much more water vapors in the atmosphere. We are not able to predict what will be the effect of such phenomena to LARC system's ability to make rain. In order to cope with this, the laser firing policy and scheme on board the satellites will need to be recalculated based on rapidly changing climate model.

References

[1] S.Henin et al. "Field measurements suggest the mechanism of laser-assisted water condensation." Nature Communications 30 Aug. 2011.

[2] Siegfried W. Janson, Henry Helvajian, William W. Hansen and Lt. John Lodmell "micro thrusters for nanosatellites" The Second International Conference on Integrated Micro Nanotechnology for Space Applications Pasadena, CA, April 11-15, 1999

[3] R.J.Stirton "The upper atmosphere and satellite drag" Journal Smithsonian Contribution to Astrophysics, Vol. 5, p.9