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Mechanism of Cooperation for the Development of a Central American Space Project – A Regional CubeSat

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Abstract

The Central American region has embarked on different endeavors related to space engineering in recent years. CubeSat missions are currently being independently developed in Costa Rica and Guatemala, with the main purpose of training the human resources, creating the know-how, and infrastructure necessary to execute end-to-end space missions. On the longer term, both groups seek to develop further small satellite missions that will allow scientists and engineers to address the needs of the region, which include remote sensing, communications, monitoring of drug trafficking, illegal fishing, assessing the impact of and preparing for climate change, among others. Both teams understand that to potentiate their capacities beyond the realm of these initial projects, cooperation among peer teams is mandatory. Due to the similar socio-economic situation of both countries and their similar level of development and geographical closeness, there exists a great potential for collaboration. In this scenario, it has been concluded that the best way to develop this collaboration is through the development of a joint space engineering project. This paper proposes a CubeSat mission that will initiate cooperation between research institutions in Central America, led by Universidad del Valle de Guatemala (UVG) and Costa Rica Institute of Technology (TEC). Previous examples of collaboration between countries of different regions in space-related projects are analyzed and discussed. A methodology developed by researchers at UVG is used to selecting the mission that would benefit the Central American region the most while considering programmatic risk and technical feasibility. This work serves as the basis for determining aspects such as spacecraft capabilities, specifications, and resources needed. Additionally, it helps define the different spacecraft subsystems and other mission features including project management, funding acquisition, testing, launch, and operations. The design philosophy is presented as well, which consists of incremental innovation, starting with the use of high Technology Readiness Level (TRL) spacecraft components from established suppliers, leading to subsystem development by universities and industry in the region. Furthermore, the distribution of responsibilities between participating organizations is defined based on the capabilities of the stakeholders.

Keywords: International collaboration, forest monitoring, emerging space nations

Acronyms/Abbreviations

ADCS	Attitude Determination and Control System
BIRDS	Joint Global Multi-National Birds
CAB	Center for Astrobiology of Spain
CaNOP	Canopy Near Infrared Observing Project
CDR	Critical Design Review
CENAT	National Center for Advanced Technology
CNES	French Space Agency
DLR	German Aerospace Center
EPS	Electrical Power System
ETHZ	Swiss Federal Institute of Technology
EO	Earth Observation
ESA	European Space Agency
EVI	Enhanced Vegetation Index

GCS	Ground Control Station
GNC	Guidance, Navigation, and Control
GPS	Global Positioning System
ISIS	Innovative Solutions In Space
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
Kyutech	Kyushu Institute of Technology
LAI	Leaf Area Index
LEO	Low Earth Orbit
MICITT	Ministry of Science, Technology, and Telecommunications
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NPR	NASA Procedural Requirements
OBC	Onboard Computer
OLI	Operational Land Imager
PDR	Preliminary Design Review
PgM	Program Manager
PI	Principal Investigator
PM	Project Manager
SESLab	Laboratory of Electronic Systems for Sustainability
SETEC	Space Systems Laboratory of TEC
SRR	Systems Requirements Review
TEC	Costa Rican Institute of Technology
TRL	Technology Readiness Level
TU Delft	Delft University of Technology
UHF	Ultra High Frequency
UVG	Universidad del Valle de Guatemala
VHF	Very High Frequency
WBS	Work Breakdown Structure

1. Introduction

The democratization of outer space has been a growing movement in the 21st century. With advances in the miniaturization of technology, countries with no existing space programs have been able to place their first satellite in orbit, creating skills and capabilities in emerging space nations. One main catalyst of this movement is the CubeSat standard, used to develop satellites rapidly, at a low cost. This specification has allowed nations such as Switzerland, Colombia, and Peru to design, build and operate their country's first satellites. Furthermore, initiatives such as the United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (KiboCube), the European Space Agency's (ESA) Fly Your Satellite!, and the National Aeronautics and Space Administration's (NASA) CubeSat launch initiatives, allow emerging space nations and universities to launch their satellite at no cost, promoting new missions and technologies for teams that could not previously afford to place their satellite in space.

Thanks to the CubeSat standard, small satellites are currently being developed all over the world, including the Central American region. Costa Rica and Guatemala are currently developing space missions, aimed to show how space technology can benefit their nations. Although both have started developing space missions, very little formal collaboration has existed between these or any other Central American nations in space activities. Similar to the scientist of the European community that created ESA to be able to compete with the superpowers at the time, the authors of this paper wish to establish a mechanism for collaboration between Central American countries to promote the development of space projects and programs that will generate results that will benefit the region and the world.

Fruitful cooperation between Central American countries will facilitate the execution of space missions. Each nation can contribute based on their expertise while costs and risks of the project are distributed. For example, Guatemala might choose to specialize in space systems, while Costa Rica in ground communications stations and Panama in scientific payloads. Collaboration between nations will not only result in a project that will have a higher impact but it will also strengthen the bonds between them, promoting further cooperation in other fields.

This paper conveys the importance of space technology for the Central American region, followed by the current CubeSat projects that are being developed. To further explain the importance of collaboration in a space project, examples of international projects, academia, and inter-agency projects are included as well. This is followed by a proposed CubeSat mission, led by Costa Rica and Guatemala, consisting of a Central American satellite. Finally, the baseline for collaboration is presented, along with the conclusions derived from this work.

2. Background

2.1 Importance of Space Technology in Central America

Between 1990 and 2014, the Mesoamerican region (defined here as the south of Mexico and Central America) has lost 5 million hectares of forest, and has experienced 36 earthquakes, 104 floods, 17 landslides, 82 storms and 21 volcanic events. Hence, Earth observation (EO) technologies have been identified as having high potential in assisting in the management of natural resources, biodiversity, and disasters in the area. The region already makes use of images acquired from space in applications such as the characterization of land-use, ecosystem dynamics and biodiversity. Additionally, EO data has been requested from other countries for at least 27 natural disasters [1]. This shows that despite of the economic conditions of the region, space technology has multiple uses and potential.

Nevertheless, it is until recently that there have been efforts within the Central American region to change from a space technology consumer to a space technology developer. For example, in 2011 a study [2] identified that, only in Costa Rica, there were at least 110 companies related to the development of aerospace products, with a combined market share of 170 million dollars. This happened despite of the fact that the industry had not self-organized towards working on aerospace applications and that there was no governmental promotion of the field. In 2014, a study done by the government of Costa Rica [3] asserted that aerospace was a key area of development in the country and promoted, for the first time, a series of policies to encourage the development of applications in industry, academia, and government. In 2016, the Costa Rican Aerospace Cluster, the first cluster of Central America, was founded by companies related to the development of applications in this field, with the cooperation of government and academia [4].

Within this context, at least two academic projects related to space technology are under development in Central America, which are described in detail in this manuscript. The teams developing these projects have identified the following conditions in the Central America area:

1. Space-based imagery is already being used in the region.
2. The current development of space technologies enable Earth monitoring applications using the CubeSat standard
3. The teams in both countries will have proven experience in the development of small CubeSat by the time this proposed second mission is started, providing a baseline for the elaboration of an application.

Other applications, like weather forecasting and telecommunication using geostationary satellites are extensively used in Central America but are out of the scope of the current technological capabilities of small satellites, and of the budgets of the countries in the area.

2.2 Costa Rican CubeSat

The Irazú CubeSat project is a joint initiative by the Costa Rica Institute of Technology and the Central American Association of Aeronautics and Space, consisting of placing a 1U CubeSat in orbit to monitor carbon fixation in Costa Rican forests. The project has two main objectives: to train scientist and engineers in the proper execution of a space mission following established standards by major space agencies, in this case utilizing the National Aeronautics and Space Administration (NASA) Procedural Requirements (NPR) 7120.5D as a baseline, and to use space technology for the benefit of Costa Rica, proving how this technology can provide solutions to developing countries. The results of the project will help with Costa Rica's goal of becoming a carbon neutral entity by 2021 and contribute to the study of climate change, a problem affecting the entire planet. Irazú is a proof of concept, which will demonstrate how a 1U CubeSat Store and the Forward system can be used to collect environmental data from remote locations [5].

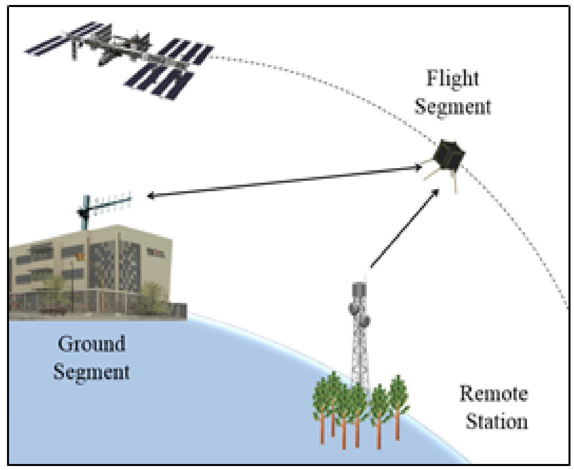

Fig. 1. Irazú project concept of operations.

The Irazú mission is divided into three segments, as displayed in Figure 1. These are the remote station, the flight segment and the ground segment. The remote station is an autonomous communication station, located in a remote forest in Costa Rica, which collects environmental data and transmits it to the CubeSat once it hears its beacon. It includes five sensors called dendrometers that will be placed on sample trees to measure their growth, collecting raw data that will be used to calculate biomass growth and carbon fixation of the experimental site. Additionally, this segment includes a meteorological station to study the correlation between various climate parameters and tree growth. The flight segment consists of a 1U CubeSat that will be launched from the International Space Station for a 6-month operation. It will act as a Store and Forward System, collecting data from the remote station, storing it in its internal memory and downloading it to the ground segment upon command. The ground segment is in charge of collecting this data, analyzing it and publishing it in an interactive website in a visually appealing fashion, to promote science and technology in Costa Rica.

The project has reached many major milestones, including the successful approval of the System Requirements Review (SRR), Preliminary Design Review (PDR) and Critical Design Review (CDR) by a committee of international experts from NASA, the Kyushu Institute of Technology (Kyutech) and the Delft University of Technology (TU Delft). Additionally, the Irazú team has successfully executed a fundraising strategy to purchase spacecraft components and launch services, including a Kickstarter campaign that raised $81,369 [6].

2.3 Guatemalan CubeSat

Universidad del Valle de Guatemala (UVG) is developing a 1U CubeSat, involving students from multiple majors and years, directed by UVG faculty. This first satellite will test a novel approach for multispectral remote sensing that could enable its implementation for targeted applications which needs are not being addressed, utilizing a CubeSat as the satellite bus. A Commercial-Off-the-Shelf (COTS) approach is being taken on most of the components of the CubeSat while the payload is being produced in-house. This payload consists mainly of a monochromatic sensor and a motorized carousel that allow for the implementation of different light filters, which in turn enable the acquisition of various types of data.

Each remote sensing application requires the collection of data at different wavelengths of the electromagnetic spectrum. For example, to monitor contamination of lakes, data collection at 444 nm, 555 nm, and 670 nm is helpful as it allows for the determination of the concentration of chlorophyll-*a* – a proxy to characterize cyanobacteria and algae presence on water surfaces. Other applications, e.g., vegetation mapping, monitoring of forest fires, etc. require data collection at other wavelengths. The payload being tested with UVG's first CubeSat will enable the changing of filters by rotating the carousel that houses them, allowing for a single sensor to acquire data that can be used for myriad applications. This CubeSat will open the field of space science & technology in Guatemala and enable the independent acquisition of remote sensing data for the monitoring and managing of its natural resources.

The Guatemalan CubeSat project started in 2014 [7] and its development will cost under $100,000. The project has passed the CDR level, reviewed by an international expert committee from different NASA centers, ESA, and universities in Europe, the U.S. and Brazil. UVG has the support from the Guatemalan Government for frequency licensing and spacecraft registration with the appropriate national and international regulating bodies.

The successful operation of the Guatemalan CubeSat could validate this accessible remote sensing technical approach, which in turn could be used for other peaceful, remote sensing applications and thus enable Guatemala and other developing countries to acquire their own custom-targeted remote sensing data and empower them to manage their natural resources.

3. Precedents

3.1 International Projects

The study of space represents an opportunity for international cooperation. Projects like the International Space Station [8], and more recently satellite consortiums like QB50 [9] are good examples of what it is possible to achieve when several countries work together for a common endeavor. One of the advantages of having multiple partners in pursuing a joint mission is the increase in the resources available to achieve it. However, multiple stakeholders are translated into multiple self-interests that need to be addressed during the operation of such projects.

The implementation of international space projects requires the use of laws and institutions at the local level to satisfy technical, but also political conditions for the stakeholders. From the sustainability perspective, having international space projects require the political support from the different countries involved, but they are also subject to the relations among countries participating in the project since it becomes a strategic asset [10]. From the technical point of view, the efficiency of the operations is a key element to sustain the project over time, especially due to the cost of maintenance and operation [11].

To implement an international cooperation framework for space exploration, there are two main inputs required [12]. One is the initial conditions, which include economic and political situation, cultural similarities, and scientific and technology access. The second input is the stakeholders, for example, the scientists, government institutions, universities, Non-government organizations, and companies, among many others. To establish a model for cooperation, the stakeholders shall agree on their scope, roles, and responsibilities beforehand, as well as their commitments to see the project through. These agreements are documented using memorandums of understanding, contracts or any formal document that enables a medium to record and track the acquired responsibilities. These documents shall also document the individual interests for the others partners to keep the visibility, and somehow, monitor the proper execution of the project. These agreements shall be consistent with the internal institutional regulations as well as the national level laws and agreements signed by the countries participating in the project.

3.2 Intra- and Inter-Agency Projects

A different type of collaborative approach is observed in larger space programs such as NASA, where more than one center can be involved in a given project. An example of this is the "MaterialsLab Open Science Campaigns for Experiments on the International Space Station", a multidisciplinary program where materials scientist from NASA's Goddard Space Flight Center work together with payload managers at NASA's Marshall Space Flight Center and biologists at NASA's Ames Research Center in support of scientists conducting investigations on board the International Space Station [13]. In this case, the strengths of different centers are combined to produce a team informed on the various aspects needed to support a successful research project on ISS. Another example is how planetary missions are designed and operated. In the case of Juno, a spacecraft currently orbiting Jupiter, the mission is managed by the Jet Propulsion Laboratory (JPL) and is part of the New Frontiers Program, managed at the Marshall Space Flight Center, while NASA's Kennedy Space Center (KSC) was responsible for launch management [14].

An example of an inter-agency precedent is the InSight mission to Mars, which is managed by NASA's Jet Propulsion Laboratory (JPL) and that includes payloads from the German Aerospace Center (DLR), French Space Agency (CNES), Swiss Federal Institute of Technology (ETH), and the Center for Astrobiology of Spain (CAB), to name a few [15].

3.3 Academic Projects

In the academic realm, international cooperation projects in the small satellite area are not as common as it may be expected, especially considering that several countries within one region may share a mutual interest. Extensive lists like the ones present in "Nanosatellite Database by Erik" [16] and "Gunter's Space Page" [17] show that a vast majority of the CubeSat projects have been developed by a single country.

Nevertheless, the increasing complexity of CubeSat missions and the shared interests of different countries have led to the proposal of multinational missions with different purposes. In this context, two kinds of academic projects are defined: projects where a partner from a developed nation cooperates with developing countries, with the objective of fostering the space capabilities of countries with no space heritage, and projects were partners already possess these capabilities and complement each other through collaboration.

An example of the former type of collaboration is the Joint Global Multi-National Birds (BIRDS) program [18], initiated by Kyushu Institute of Technology in Japan, consist of a constellation of 5 1U CubeSats developed by students from Japan, Ghana, Mongolia, Nigeria, Bangladesh, and Thailand. This activity had the particularity of a strong Japanese cooperation (the students were located in Japan) and had the purpose of creating capabilities in developing nations in the area of space technology.

The QB50 mission [9], a constellation of 50 CubeSat from multiple international academic partners, exemplifies the latter type of collaboration. In this mission, every partner develops at least one CubeSat. The main mission is to study the variations of certain parameters in the lower thermosphere (90-320 km of altitude). Here, a scientific institution as the "von Karman Institute for Fluid Dynamics" works as the project manager, coordinating aspects such as the scientific payload and launch, while every academic entity provides the development and construction of the satellite.

Another example of collaboration with the objective of developing human capital is ESA' ESEO project. The program aims to provide students across Europe with hands-on experience in all the levels of a space project's lifecycle. With this purpose, a company, ALMASpace S.r.l., was selected as system prime, and students from 10 different ESA-member states' universities worked in the development of the spacecraft.

Both Guatemala and Costa Rica have developed capabilities as a result of their first space mission and understand that through international collaboration, they can generate projects and programs with higher impact on the region rather the working individually.

4. Proposed Project

4.1 Mission

The methodology developed by Zea et al. [19] was used to select a mission that will benefit the Central American region in an objective, systematic and scholarly fashion. This tool enables to quantitatively compare different potential missions taking into account programmatic risk, technical feasibility, relevance, required resources, and benefits. In the case of the Central American CubeSat, three options were down-selected and assessed via the methodology: (i) forest mapping, (ii) volcanic monitoring, and (iii) vegetation mapping.

The forest mapping mission speaks of differentiating areas covered by trees from those utilized for everything else: agroindustry, cities, and deserts, among others. According to the World Bank, 54% of the Costa Rican territory is covered by forest, while this value is 33% and 41% for Guatemala and the Central American region, respectively [20]. The importance of this application stems from different aspects, as the frequent acquisition of this type of data can enable the immediate reaction to illegal deforestation, conservation of biodiversity [20], characterization of CO_2 storage [21], and protecting the region's natural heritage, among others.

Parameter	Importance
Natural resources	4
Relevance	4
Budget	4
Risk	3.9
Education	3.7
Applied Research	3.6
Impact on personnel	3.6
Alignment w/other projects	3.3
Technology development	3.3
New markets	3.1
Team leadership	3
In-house knowledge	2.9
Natural disasters	2.9
Basic Research	2.7
External alliances	2.7
Marketing	2.7
New technologies	2.7
Time	2.7
Technical / Infrastructure	2.6
Products / services	2
Health	1.9
Human resource retention	1.9
Job creation	1.9
Economic productivity	1.7
New customers	1.6
Return of Investement	1.6
Exports	1.4
Intelectual Property	1.4

Fig. 2. Importance levels (1-4) of the parameters taken into account for the mission selection.

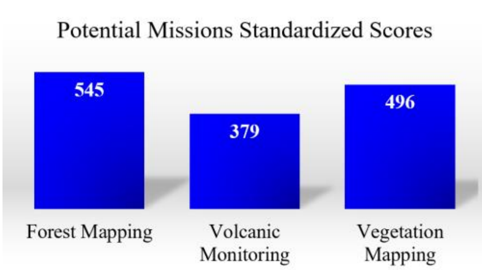

Fig. 3. Standardized scores for each of the missions assessed with the methodology. Vegetation mapping and volcanic monitoring accrued 91% and 70% of the forest mapping score, respectively.

According to the Smithsonian Institution's Global Volcanism Program, there are 500 volcanoes in the Central American region, and during the first decade of this century, there were 41 eruptions [22]. The volcanic monitoring application could serve to acquire plume altitude, ash particle density profiles and other parameters that may aid in planning to mitigate human and infrastructure losses during a volcanic eruption.

Vegetation mapping enables the characterization of soil use by differentiating land coverage by crops from urban areas, forest, etc. Furthermore, it can help discern from one crop to another, assisting in the governmental and agro-industrial strategic planning; it also helps understand natural and human-made environments at larger scales [23].

The methodology was implemented by (i) assigning importance levels to 28 different parameters (Figure 2), (ii) designating normalized values for each parameter on each of the three potential missions, (iii) calculating the standardized score of each application. This exercise resulted in the selection of the forest mapping mission (Figure 3). Aspects taken into consideration include the region's interest in protecting its natural resources, understanding the effects of and preparing for climate change, and the academic nature of the institutions implementing the methodology, among others.

4.2 CubeSat Components

CubeSats are complex systems integrated with specialized components that perform a specific function and withstand space and launch environments. Engineers must take into consideration mission requirements and select the components needed and their characteristics. These elements vary from one mission to another and may be developed in-house or bought off the shelf, even though most CubeSats maintain a set of modules that are basic to complete a space mission [24, 25].

The electrical power subsystem (EPS) must supply energy to the electrical components. EPS is usually composed of three main systems: harvesting system, storage system and management and distribution system. The harvesting system must collect power from a source of energy and transform it into electrical energy. For CubeSats, the most common form of this component is photovoltaic solar cells. The storage system allows operation when harvested power is insufficient. Usually, this system is made of battery cells connected in series and/or parallel. In some cases, there is no harvesting system, and the satellite is deployed only with stored energy. Power management and distribution are done through EPS control by the on board computer (OBC).

The structure components must protect and accommodate all other subsystems according to their function, relationship, and requirements from standards. Its design is defined by standards, launch loads, and space environment and developers must adapt to these. These satellites can scale from a cube to an assembly of cubes (1U to 6U+) and are usually covered by solar cells. This module varies in the way that the main structure accommodates and attaches each of the components into place, by using fasteners or adhesives, and also in how they are manufactured, from a solid block, several pieces, or a metal sheet. Most developer decisions impact only the internal composition since the standards control most of the design.

The thermal control system is used to maintain a temperature range in which the CubeSat's components can perform correctly. This module might use an active or passive method and therefore require electrical energy or not. The most common are the passive option since power available in a CubeSat is scarce. Special coatings, polymeric and aluminum tape, multi-layer insulation and radiators are popular components for this module [25].

The communications module is responsible for transmitting the data gathered in space and sending it back to Earth to the Ground Control Station (GCS), where the information can be analyzed and used for research or commercial purposes. It is composed of transceivers and antennas in bands like VHF/UHF, L and S. This module not only transmits data about the CubeSat state and all the sensors in it but most importantly, data acquired by the payload. It also receives and interprets data from its surroundings, a GCS or another satellite of a constellation, so that other components can function correctly or even change their programming. To support a CubeSat mission, at least a GCS is needed to send commands are receive data from the satellite.

The Command & Data Handling subsystem ensures appropriate communication between the different components of the satellite, and the satellite and its GCS. The component responsible for managing this flow of information is the On-Board Computer (OBC). This module is usually composed by microprocessors, which perform the computing and data storage and provide the input and output interfaces that conform this network. The Guidance, Navigation, and Control (GNC) (sometimes called Attitude Determination and Control System (ADCS)) determines the satellite's orbit position, orientation and controls it to ensure that the satellite is oriented correctly. This subsystem enables the proper pointing of solar cells, antenna, and sensors per mission's requirements. Common components are magnetic torques, reaction wheels, control-moment gyros, star trackers, horizon sensors, hysteresis rods, gyroscopes, GPS receivers and sometimes, thrusters [24, 25].

All of these subsystems enable the operation of a payload, which is responsible for the mission's scientific or technical mission (except for the cases of technology demonstrators). The nature of the payload varies depending on the CubeSat's mission, which can include Earth observation, space environment characterization, astronomy [19], or space life sciences, to name a few [26].

4.3 Scientific Payload

Since the year 2000, global forest loss has been over 2.5 million km^2, with losses concentrating on tropical regions. All countries that have committed to the Paris Agreement are required to have accurate and consistent data of changing forest areas, stratified by forest type. These aspects evidence that forest mapping is a necessity not only for internal means but also for external affairs [27].

Forest and vegetation mapping have been developed using satellites such as Terra, Landsat, GeoEye-1, IKONOS, QuickBird, WorldView and constellations of satellites like RapidEye and SPOT. These collect data with multispectral sensors like the Moderate Resolution Imaging Spectroradiometer (MODIS), Operational Land Imager (OLI). According to Hossain (2016), at least eight studies involving forest issues have been developed using this data in Mesoamerica with topics like mapping and forestation [28, 29, 30, 31].

The Canopy Near Infrared Observing Project (CaNOP) states that forest studies depend on several indexes such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Leaf Area Index (LAI) and more. Most of these can be calculated by using remote sensing data from the blue, green, red, and Near Infrared (NIR) bands. Therefore, a feasible approach for a new payload that could be used for forest mapping will be to replicate the characteristics of sensors like MODIS and OLI (see Table 1) [32].

Table 1. Wavelengths per band of satellites used for forest mapping [33-42]

	Blue (nm)	Green (nm)	Red (nm)	Near Infrared (nm)
Terra (MODIS)*	405-493	526-565	620-683	743-877
Landsat (OLI)	450-510	530-590	630-670	850-880
GeoEye-1	450-510	510-580	655-690	780-820
IKONOS	450-520	520-560	630-690	760-900
QuickBird	450-520	520-600	630-690	760-900
WorldView	450-510	510-580	655-690	780-920
RapidEye	440-510	520-590	630-685	760-850
SPOT	430-470	500-590	610-680	780-890

* MODIS more than one band for each spectral region

4.4 Other Aspects

To execute any project, it is critical to implement basic project management principles, such as a Work Breakdown Structure (WBS), a budget and a schedule, to guarantee its success. The WBS is essential to define the roles and responsibilities of each partner and is an important exercise that will allow each actor to understand what they are providing. Usually, for a

CubeSat mission, there exists one project manager, a principal investigator, and a systems engineer.

Testing and certification of the spacecraft can be done in two ways: by purchasing equipment to perform the tests required (vacuum chamber, shaker, thermal test bed, among others) or using a third party to perform the tests. The former option involves a considerable investment by one of the partners in lab equipment but will allow the team to conduct future tests at a reduced cost. The latter option is less expensive but still, leaves the dependencies on third parties for future missions. These types of services are provided by companies, such as ISIS or GomSpace, or universities, such as Kyutech. The correct option will depend on the budget defined for the project.

The launch mechanism is an important aspect of the mission since it will determine coverage time, duration and spacecraft lifetime. When operating in Low Earth Orbit (LEO), placing the CubeSat at a very low-altitude orbit will result in a short lifetime, since the orbit will continuously lose energy due to atmospheric drag. Conversely, placing it in a high-altitude orbit will result in higher radiation doses, risking the subsystems lifetime. The ideal orbit for a Central American satellite would be close to equatorial since the spacecraft would be in the line of sight of the region for every revolution. At 500 km altitude, the spacecraft could easily operate for various years without violating the International Orbit Disposal Guidelines, which states the satellite cannot be in orbit more than 25 years after retirement. Launches to this type of orbit are rare and often result in high-cost fees. More feasible options include launching as a secondary payload, deployment from the International Space Station or using dedicated small-satellite launchers, such as the Electron launch vehicle from Rocket Labs.

An interesting option for this project is to apply to the KiboCube program managed by the United Nations and Japan since they provide free launches from the International Space Station to emerging space nations. Although the lifetime of the spacecraft would be a few months, it would be enough to accomplish the project's high-end goals.

Finally, the operation is a task in which each country would contribute equally, having a ground station and mission control in each university, collecting telemetry, scientific data and verifying the proper functioning of the spacecraft. The operations team would welcome international collaboration from other universities or amateur radio operators, in the form of collecting telemetry of the satellite around the world and sending it to the partner universities via the internet.

5. Baseline for Collaboration

5.1 Consortium

Developing projects at the regional level requires the establishment of legal figures, since the stakeholders need to define, agree and document their expected inputs and outputs to the project. For our case, we assess the possibilities of implementing a legal entity that allows partners and stakeholders a flexible mechanism for cooperation. In Section 3.1, we have studied other international space projects, and defined that the most efficient way to cooperate for the development of our selected mission concept is by creating a Central American Consortium for Forestry Monitoring, which will be focused on providing information for government and private partners to define strategic planning.

By consortium, we understand "a group of separate businesses or business people joining and cooperating to complete a project." These partners include academic institutions, government institution, companies from industry, and non-government organizations. For the forest mission selected in this work as a case study, we have identified the following stakeholders as part of the potential consortium:

Academic Institutions:

- Costa Rica Institute of Technology (TEC): To provide expertise in space systems engineering, forestry instrumentation design, and electronic engineering for subsystem development.
- Universidad del Valle de Guatemala(UVG): To provide expertise in mechanical design for satellite structure, as well as to lead the payload development for the satellite.
- Others to be defined.

Government Institutions: To provide funding and strategic planning based on the data collected by the satellite. Among these organizations can include:

- Ministry of Environment from Costa Rica
- The Guatemalan National Council on Protected Areas (CONAP)
- Centro Nacional de Alta Tecnologia de Costa Rica (CeNAT) for post processing the information gathered.
- Others to be defined

Non-Government organizations: To promote and provide outreach for the project. For example, ACAE, ESAI, Climate change Observatories, among others.

Industry partners: for instance, the Costa Rican Aerospace Cluster to provide expertise on components and subsystem manufacturing.

In summary, the consortium will be established to address the interest of stakeholders to increase the knowledge about forest coverage in the Central American region. Later we discuss how this consortium will break down the work and provide funding to achieve its mission.

5.2 Work Breakdown Structure

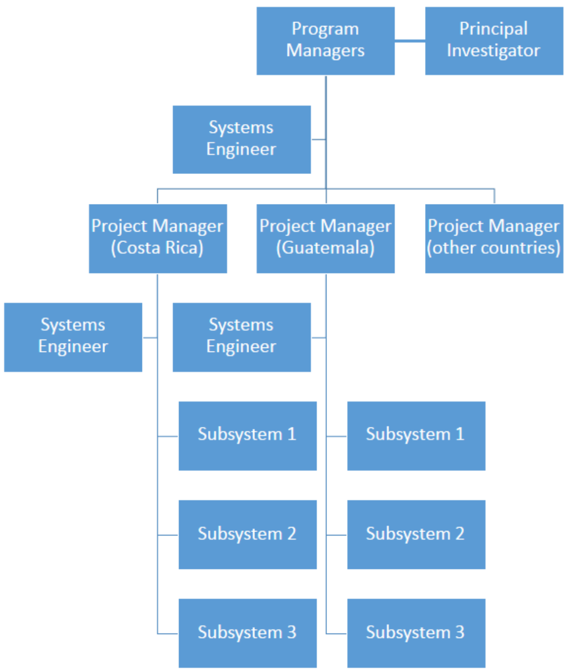

Fig. 4. Work Breakdown Structure of Central American Space Project.

The Work Breakdown Structure (WBS) of the project is a critical component when defining mechanisms of cooperation since it allows the team to distribute tasks and assign responsibilities to each organization. The proposed WBS is presented in Figure 4. At the top of the diagram is the principal investigator (PI), defined as the person or entity that will act as the main scientific expert in the project. The PI will define the requirements of the mission and the scientific data, which are the drivers for designing the spacecraft and payload. The program managers (PgM) will be responsible for the overall administrative component of the project, including budget and schedule management, top-level task distribution, and ensuring its overall success. For this project, there will be one PgM representing each country. Additionally, for each country there will be one regional project manager (PM), ensuring the proper execution of the tasks that have been assigned to their respective country. The top-level systems engineers, which report to the PgMs, will act as interfaces between regional PMs to allow proper communication between countries. Regional systems engineers will help to establish connections between the subsystems that are being developed in their institution. Furthermore, the WBS shows that the project is open to more Central American countries interested in participating, either creating subsystems for the spacecraft of establishing a ground station in their region that will allow more access time to the CubeSat.

5.3 Funding

For this project, a distributed fund raising strategy is proposed. Every single institution participating in this project will be in charge of obtaining the financing for every subsystem, and the researchers assigned time within the context of every institution. Nevertheless, there are general expenses for this project, notably the testing and launch of the satellite. The multinational characteristic of this project will be taking into account in this project to apply for Central American level funding for research. This founding exists both in the context of promoting joint research project for international cooperation at a regional scale and the specific application of environmental monitoring.

5.4 Spacecraft

The complex nature of a satellite (as described in Section 4.2) enables the segregation of work in a per-subsystem fashion. In the case of the mechanism of cooperation here proposed, the responsibility for the subsystems was assigned as follows: Costa Rica will oversee the development of the On-Board Computer and Command & Data Handling, the Energy and Power System, and the Attitude Determination & Control System. Guatemala will be responsible for the Structure and the Payload. This assignment of roles and responsibilities stems from each group's strengths and strategic interests. For example, Costa Rica is interested in becoming a developer of ADCS at a global level, and Guatemala has similar intentions with regards to sensors. By working together, these countries can each specialize in different aspects of satellite technology that are complementary. This leaves two other components, Communications and Thermal, unassigned. This serves as a room for growth regarding collaborating partners, which - as mentioned before - enables the participation of other countries in the region. Similarly, the Ground Controls Stations established in Costa Rica and Guatemala will be available for this satellite's operation, but other institutions in the area are also welcome to participate by building their GCSs and connecting them to this Central American network.

5.4.1 Structure

UVG is developing the structure for the first Guatemalan satellite in-house. The design has already been validated with software analysis and will be tested in a laboratory. The university has the capabilities and technology needed to accomplish the structure requirements of the CubeSat standard.

5.4.2 Onboard Computer

TEC has been working the creation of a secondary OBC for Project Irazú, in collaboration with Imagine XYZ, a company founded by TEC Graduates. The work was done towards the establishment of this new device, and the capability to create printed boards may be used to build the device. Also, the cooperation between this newly created company and the university allows both institutions to apply for not-refundable resources that would finance the hardware and the engineering time. Imagine XYZ has been granted this kind of funding in the past with great success.

5.4.3 Electrical Power System

The Laboratory of Electronic Systems for Sustainability (SESLab) of TEC had developed a design for an EPS in the context of Project Irazú, even when a commercial part was used to reduce the risk in this first mission. This means that there is a preliminary design already in place for this part. The capabilities of TEC in creating printed circuit boards enables the possibility of building this part in-house.

5.4.4 Attitude Determination and Control System

The Space Systems Laboratory of TEC (SETEC Lab) has as one of its specialties the ADCS design. The team of the laboratory is already designing an ADCS system for another satellite project still to be revealed but will have experience in creating the system when this project starts its preliminary design phase.

5.4.5 Scientific payload

UVG is developing the payload of the Guatemalan CubeSat (as described in section II.III). The payload has the capabilities of acquiring data at different wavelengths and thus can adapt to several missions.

6. Conclusion

Mechanisms of collaboration for a Central American space project were defined in this report, including crucial aspects such as the WBS, distribution of tasks and funding strategies, among others. Through a selection methodology, it was found that the CubeSat mission that was best for the region focused on forest monitoring. Additionally, the project is designed to allow participation from various partners, hopefully involving more countries from Central America that wish to develop their capabilities in satellite missions.

The authors of this paper visualize the work presented as the first step towards a sustainable space program between Central American countries. Both Costa Rica and Guatemala already possess the capabilities to develop and execute small satellite projects, evidenced by their advances in their respective missions. The next logical step is to work towards a regional CubeSat, with a larger team, which will have a higher impact on the region. Furthermore, the authors intend that collaboration of this type will strengthen bonds between neighboring countries and will help further collaboration not only in the aerospace field but different areas as well.

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