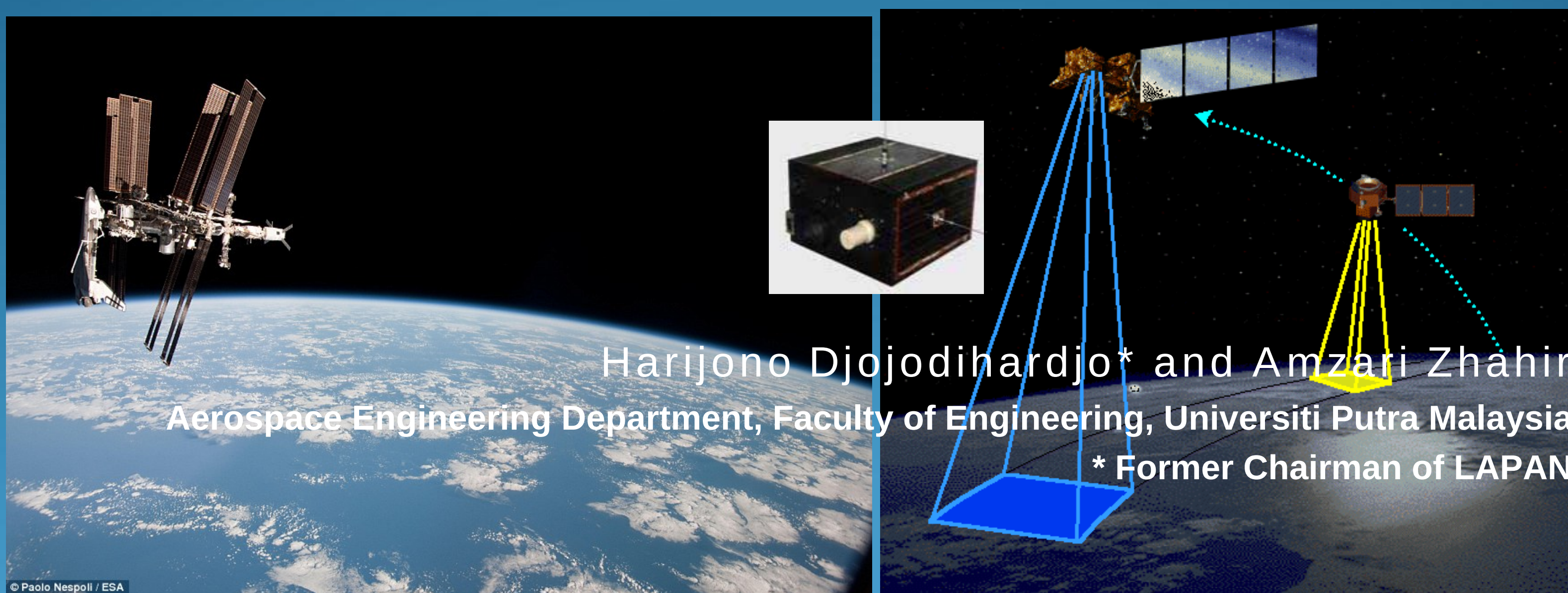
EQUATORIAL RESOURCES AND ENVIRONMENTAL MONITORING, HUMAN SPACE TECHNOLOGY INITIATIVES AND LOW EARTH ORBIT SPACECRAFT FORMATION FLYING



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SYSTEMATICS

- INTRODUCTION
- REVIEW OF TROPICAL RESOURCES SATELLITE MISSION AND OBJECTIVES
- INDONESIAN HUMAN SPACE TECHNOLOGY INITIATIVE; PAST, PRESENT, FUTURE
- INDONESIAN MICROSATELLITE TECHNOLOGY INITIATIVE-LAPAN
- CONSIDERATIONS FOR FORMATION FLYING CONSTELLATION
- RELATIVE BOUNDED MOTION
- THE DELTA-V BUDGET FOR FORMATION FLYING MANEUVER
- SPACECRAFT FORMATION CONFIGURATION DESIGN FOR TROPICAL ENVIRONMENTAL MONITORING
- ANALYSIS AND DISCUSSION BASED ON GROUND-TRACK OF A LEO SPACECRAFT FORMATION AND REMOTE SENSING APPLICATIONS
- CONCLUDING REMARKS

INTRODUCTION

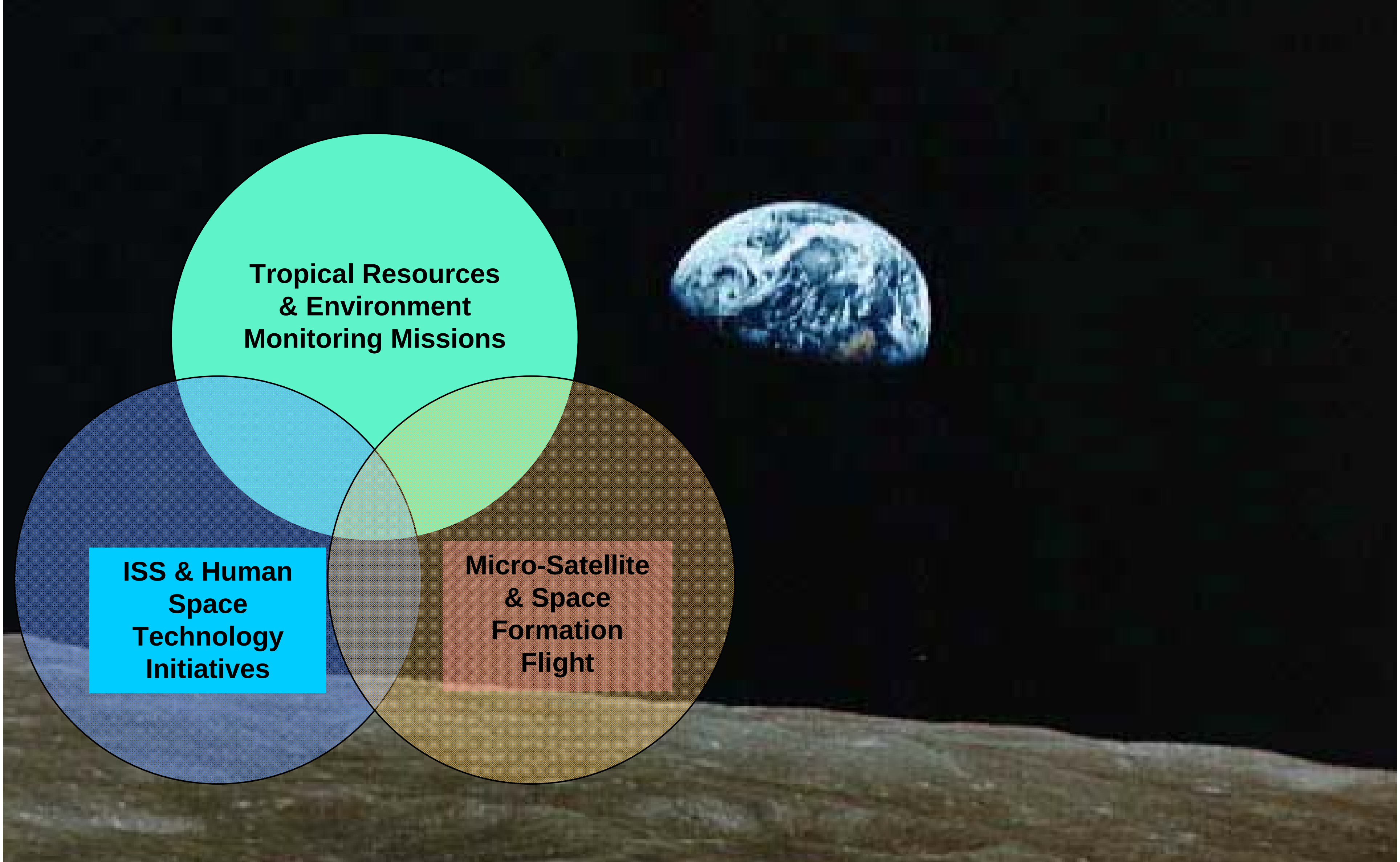
- Tropical Earth Resources Satellites and a large host of operational satellites with similar missions and high-definition three-dimensional images has been attractive for many equatorial countries, and motivated studies related to Near-Earth Spacecraft Formation Flying for Earth Pointing Tropical Environmental Monitoring.

- Progress in space exploration and technology, in particular with the International Space Station joint international efforts, has prompted further fundamental research, among others microgravity research as related to direct human interests.

- Within the perspective of the United Nations Office of Outer Space Affairs and Space Applications Program Human Space Technology Initiatives , a comprehensive account is made to review past and ongoing activities in Indonesia related to space applications and technology of direct interest to human development.

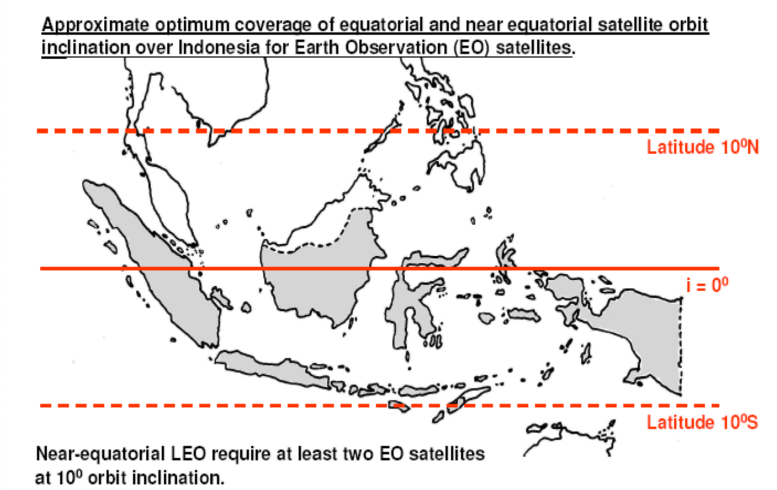
- The activities reviewed are focused on resources monitoring and disaster mitigation, human space technology activities as related to the benefits of micro-gravity environment to food, health and materials applications, and satellite technology development for enabling local capabilities in specific oriented needs as well as capacity building for future development.

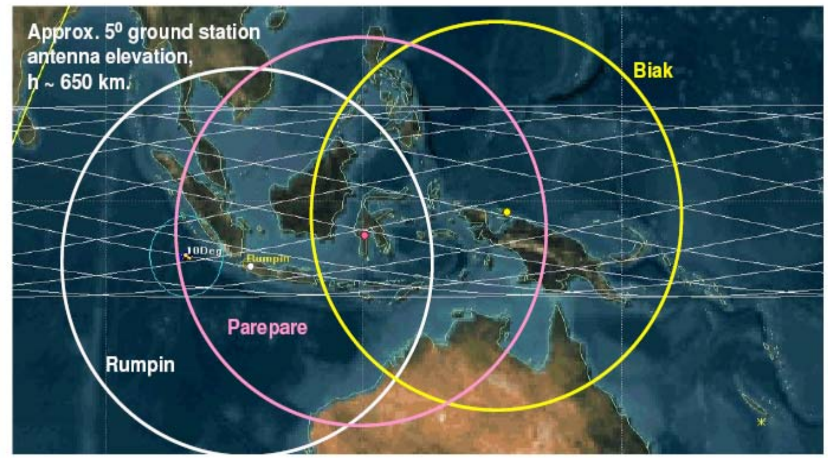
OVERVIEW



Tropical Resources & Environment Monitoring Missions
ISS & Human Space Technology Initiatives
Micro-Satellite & Space Formation Flight

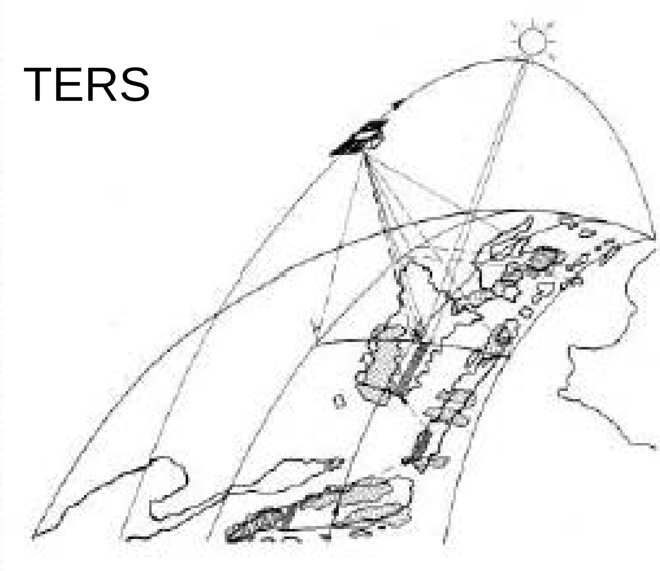
TROPICAL RESOURCES & ENVIRONMENTAL MONITORING SATELLITE MISSION



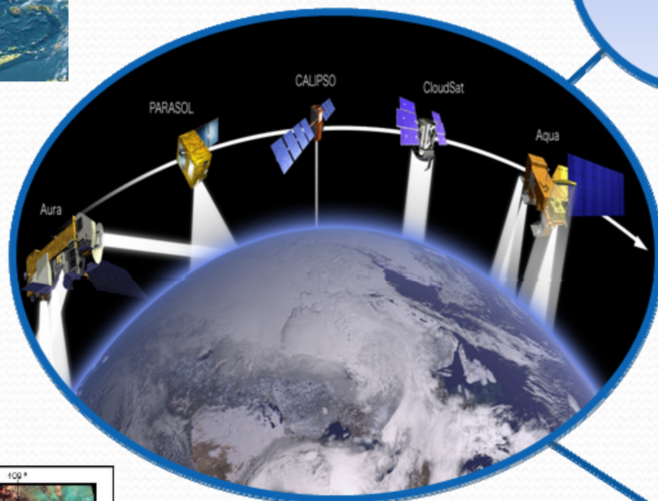


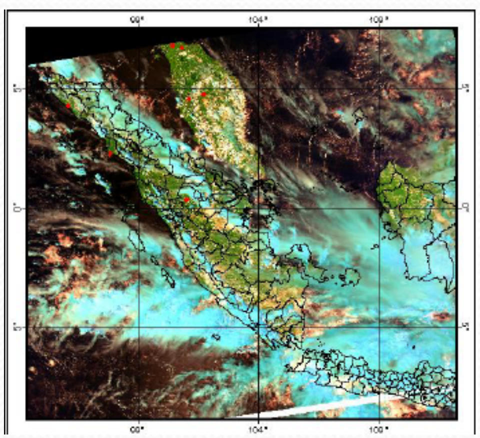
- Motivated by the Indonesian Government decision to launch the Domestic Satellite Communication System in 1976, a Capacity Building Study is carried out by LAPAN.
- One such outcome in that direction is the concept of an equatorial orbit tropical resources satellite [Salatun, Djojdihardjo & Alisyahbana, 1975], followed by related cooperative studies (Tropical Equatorial Resources Satellite – TERS).

TERS



TROPICAL RESOURCES & ENVIRONMENTAL MONITORING SATELLITE MISSION





Tropical Earth Resources Satellite (TERS)

- Netherlands-Indonesia Study on TERS (1978-1980)
- LAPAN-TUBSAT (1999-2007) & onward

International Joint Ventures

- TRMM (NASA-JAXA)
- CBERS (China-Brazil)
- DMC (Surrey-Algeria-Nigeria-Turkey-China)

Earth-Observation 1 (EO-1)

- Landsat 7
- Formation flying
- Promote nationwide technology teamwork

INDONESIAN HUMAN SPACE TECHNOLOGY INITIATIVE; PAST, PRESENT, FUTURE

Indonesian utilization of sustainable Domestic Satellite Communication System

- contracts with Hughes Space System with related offsets
- Competitive offers from other European countries
- Cooperation with other countries
- Cooperation between Hughes Space System with Indonesian Aircraft Company for future Domestic Satellite Communication System

Indonesian utilization of Remote Sensing Services, started with LANDSAT

- LANDSAT Ground Station in Pare-Pare
- Utilization of SPOT
- Remote Sensing for various Applications

Establishment of Space Meteorology in the National System

INDONESIAN ASTRONAUTS PROGRAM

- Established within Domestic Satellite Communication Program
- Two astronauts (Female and Male) were selected in 1984-1986 time frame
- It was conceived that the Indonesian Astronaut would serve as mission specialists.
- Within the microgravity research, it was conceived to investigate the influence of microgravity environment on certain microorganism

* Postponed indefinitely due to space shuttle mishap

Current activity within the Human Space Technology Initiative (HSTI) launched under the framework of the United Nations Program on Space Applications.*

- Cooperation between JAXA and LAPAN and Institute of Technology Bandung (ITB) on microgravity space biology research

- Cooperative activities prompted LAPAN and ITB to develop clinostat for microgravity simulation

- Other cooperative activities include educational aspects for ISS environment utilization, i.e. within the Space Seeds for Asia Future (SSAF) program incorporating various countries: Japan, Indonesia, Malaysia, Thailand, and Vietnam by selection of certain seeds/ grain to be placed in ISS microgravity environment. Later on these seeds are further investigated by high-school students by planting them in local environment (2010 – 2011).

- Comparative studies are carried out between seeds treated in clinostat and otherwise.

*Djamaluddin, Thomas, LAPAN, private communication, November 2011

INDONESIAN MICROSATELLITE TECHNOLOGY INITIATIVE-LAPAN**

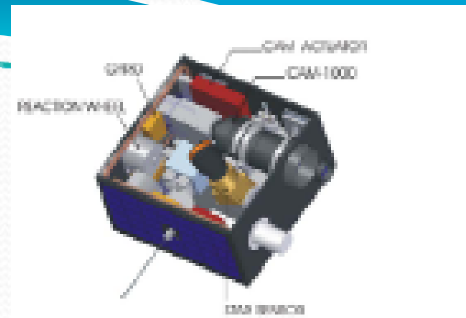
- LAPAN in cooperation with Technishe Universitaet Berlin has developed and launched 57 kg LAPAN-TUBSAT microsatellite or LAPAN-A1 satellite.

- The satellite was launched in January 2007 in cooperation with ISRO.

- Up to the present moment the satellite is functioning well and delivers significant images, and has been instrumental in convincing the stakeholders of the potential and down-to-earth benefits of domestically conceived satellite and the need for space technology capacity building.

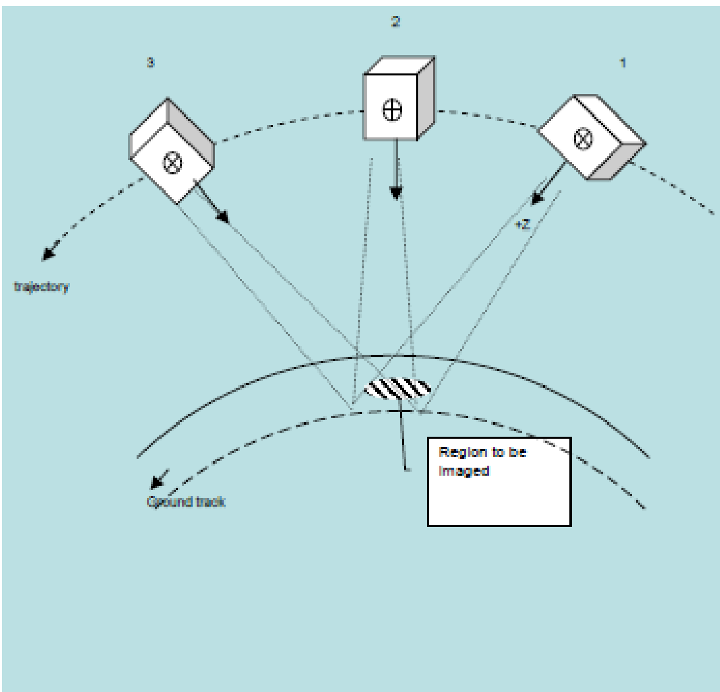
** Hardhienata, Soewarto, LAPAN, private communication, November 2011

LAPAN-TUBSAT Micro-Satellite Attitude Control Strategy



Sensor and control system

Target-locking Imaging



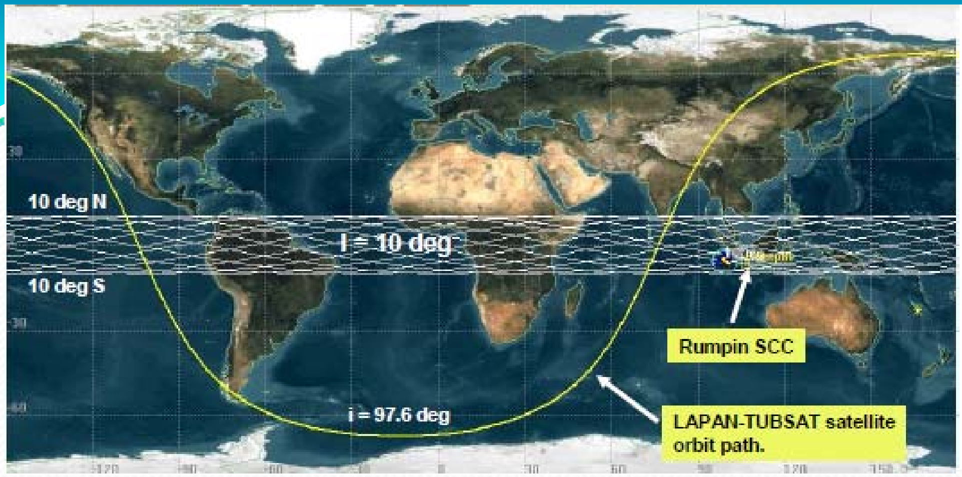
From Kadri, Toto M. and ,Salatun, Adi S., Indonesian LAPAN-TUBSAT Micro-Satellite Development, Asia-Pacific Regional Space Agency Forum (APRSAF-14), Main Theme: Space for Human Empowerment, 21-23 November 2007, Bangalore, INDIA

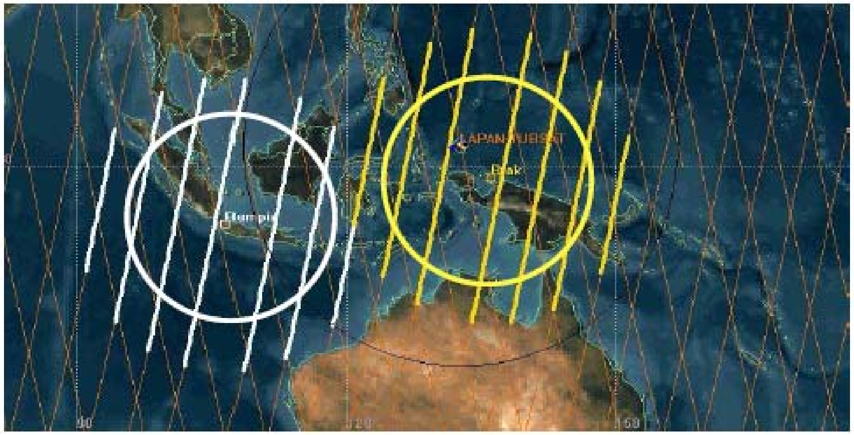
The satellite may keep its camera pointing to a certain region during its flight. Its initial pitch and pitch rate is managed so that +Z axis points to the designated point.

The operation of two cameras, the wide angle camera and the high resolution camera would enable the users to make the selection of the object to be captured interactively.

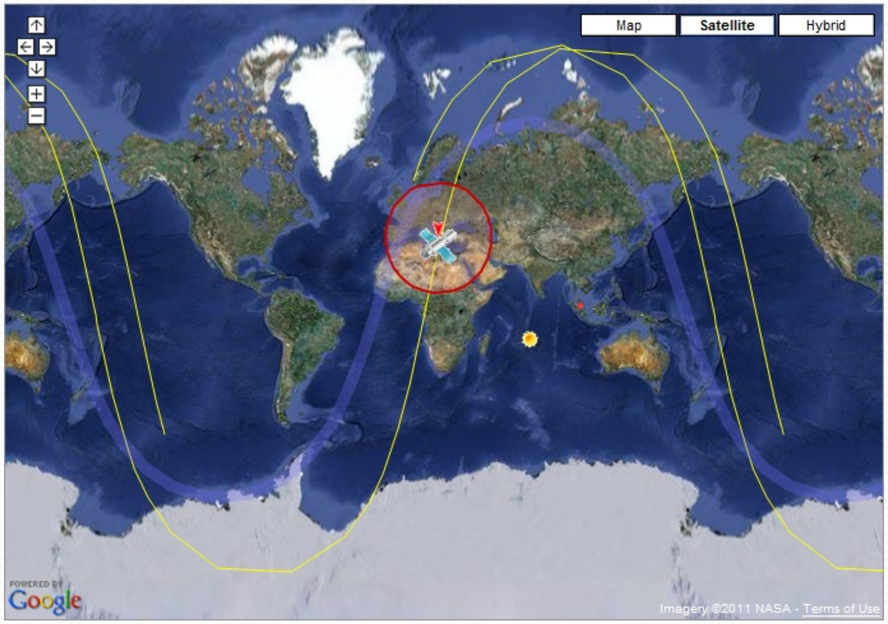
The wide-angle camera is used to determine and select the general location of the object by watching specific terrain. The high-resolution camera is used to zoom in to the area, to get better detail of the image (such as volcano, transportation infrastructure etc).

LAPAN-TUBSAT also has a free tumbling option (deep sleep mode), in which all system is switch OFF except the OBDH and TTC (in the receiving mode). By doing so, the satellite will nutate naturally and use very minimal power.





LAPAN-TUBSAT Micro-Satellite Orbit

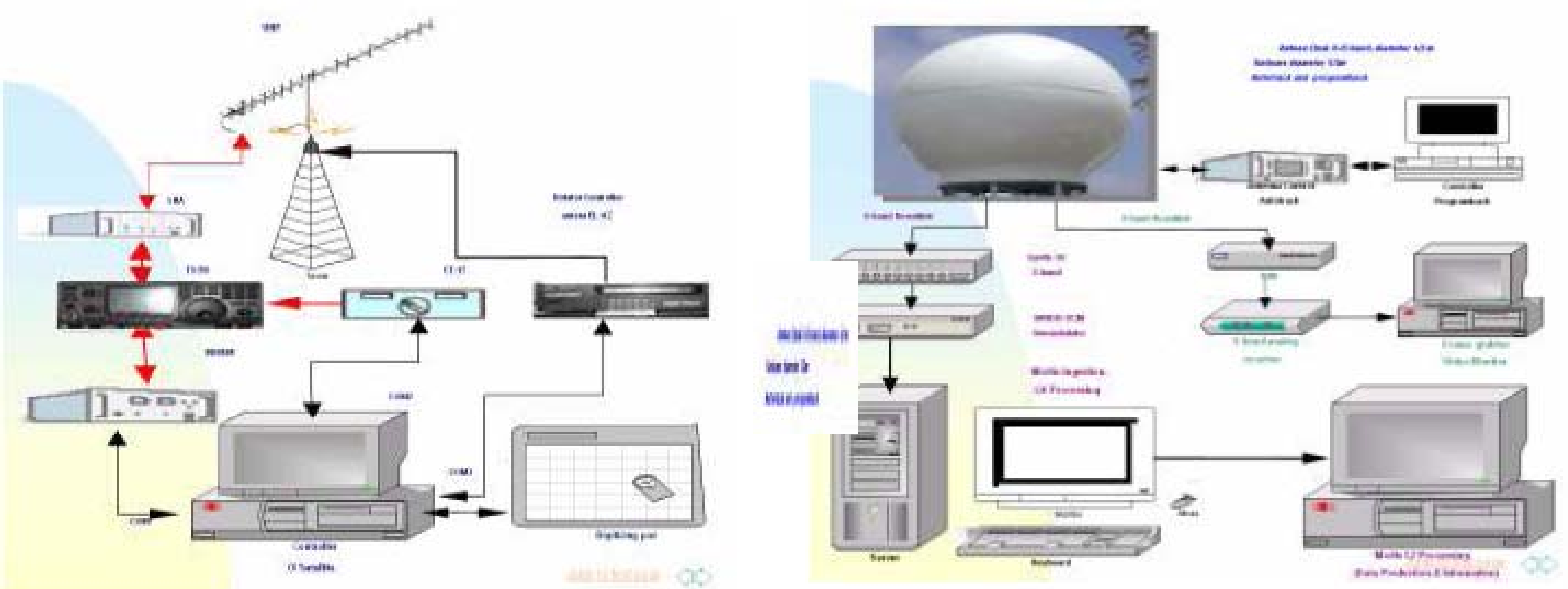


LAPAN-TUBSAT ground-track from NORAD satellite tracking (9 Nov 2011)

- The micro satellite is in an altitude of around 630 km with 97.60 inclination and period of 99.039 minutes.
- The longitude shift per orbit is about 24.828 degree.
- Its ground track velocity is 6.744 km/s with an angular velocity of 3.635 deg/s, and a circular velocity of 7.542 km/s.
- LAPAN-TUBSAT satellite performs 14.5 earth revolutions each day.

LAPAN-TUBSAT Micro-Satellite

GROUND STATION



LAPAN-TUBSAT TTC and S-Band Ground Station

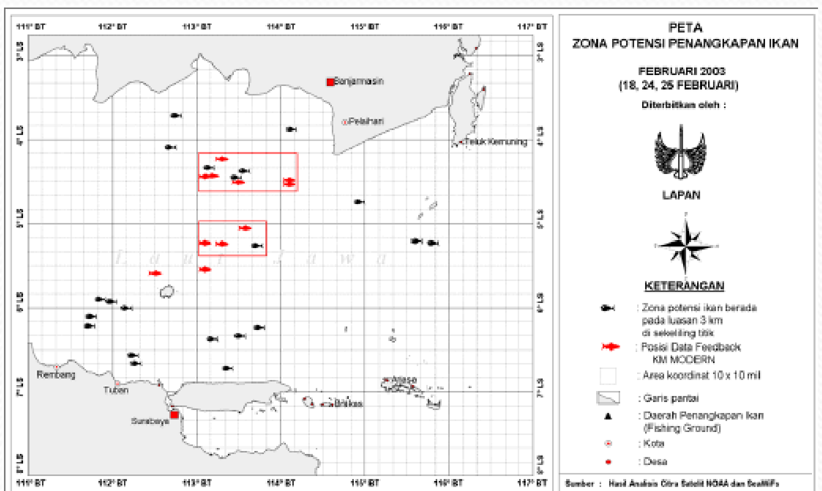
LAPAN-TUBSAT ground station consists of two systems: one is the S-band system to receive the video image from the camera payload, and the other is the UHF TTC system to send command and receive telemetry from the satellite.

From Kadri, Toto M. and ,Salatun, Adi S., Indonesian LAPAN-TUBSAT Micro-Satellite Development, Asia-Pacific Regional Space Agency Forum (APRSAF-14), Main Theme: Space for Human Empowerment, 21-23 November 2007, Bangalore, INDIA

SAMPLE APPLICATIONS OF IMAGES

Flood Prediction

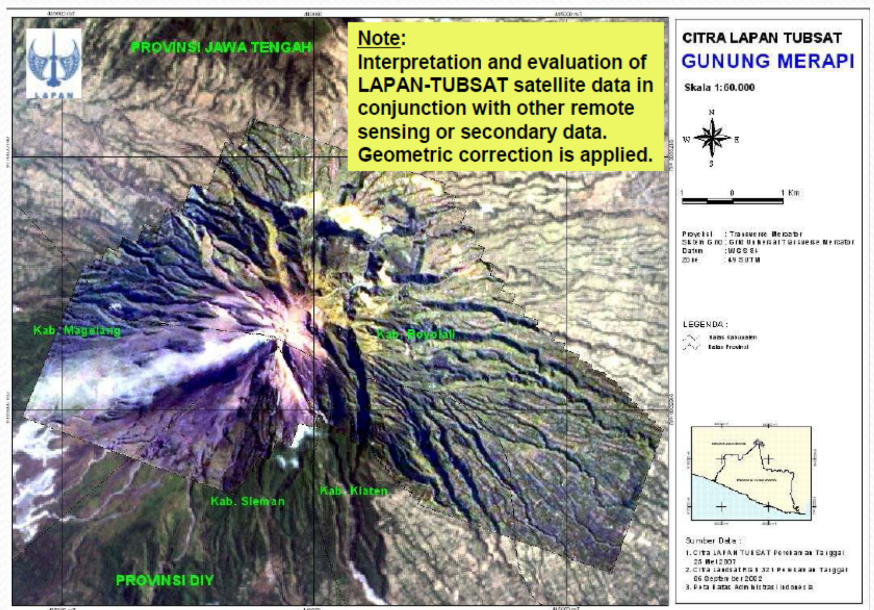
Potential Fishing Area



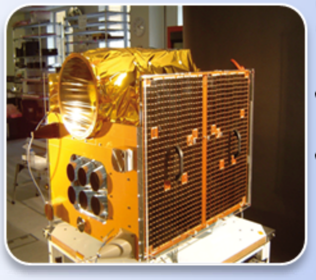
From Kartasasmita, Mahdi, Earth Observation Activities in Indonesia,Third GEOSS Asia-Pacific Symposium, Kyoto, Japan, 4-6 February 2009

Volcanic Eruption Monitoring

Mt. Semeru
Video stitch image,
LAPAN-TUBSAT
September 2007



COTS AND SMALL SATELLITE TECH DEVELOPMENT PROMOTES IN-COUNTRY SPACE TECHNOLOGY DEVELOPMENT



Small Satellite

- cost-effective local development of small satellite
- technology teamwork

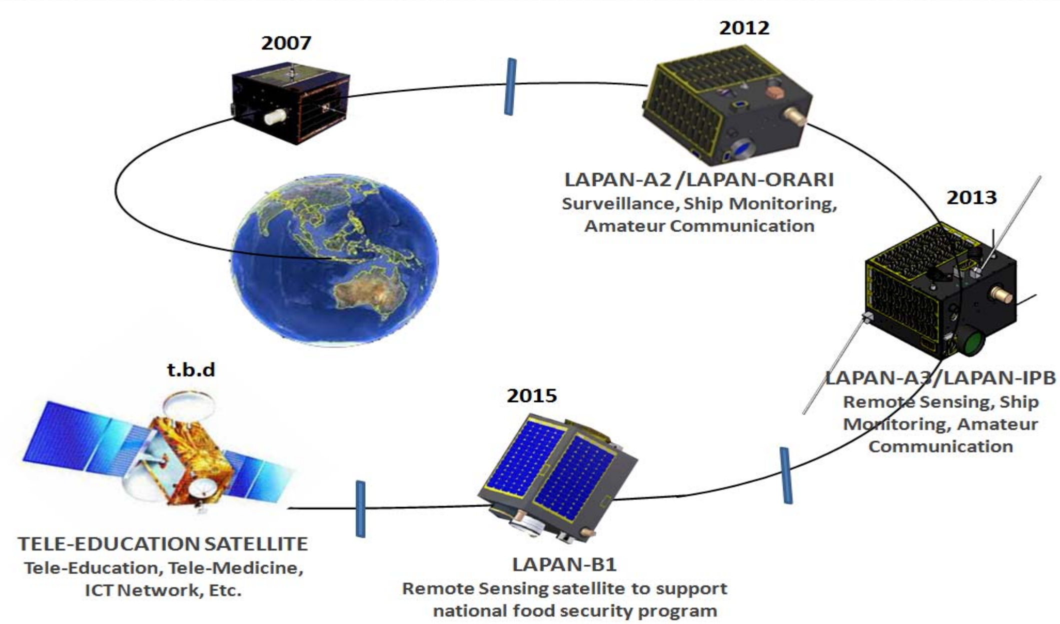
Technology Access

- ready-made
- available for sale, lease, or license to the general public

Cost

- alternatives to in-house developments or specific government-funded developments
- products may offer significant savings in procurement and maintenance

INDONESIAN MICROSATELLITE TECHNOLOGY INITIATIVE-LAPAN ONGOING ACTIVITIES**



NOTE:

ORARI- Indonesian Amateur Radio Organization

IPB – Agricultural Institute Bogor

Based on experience gained from LAPAN-TUBSAT program, LAPAN Stellite Technology Development center will continue development of Microsatellite within the 2008-2013 time frame.

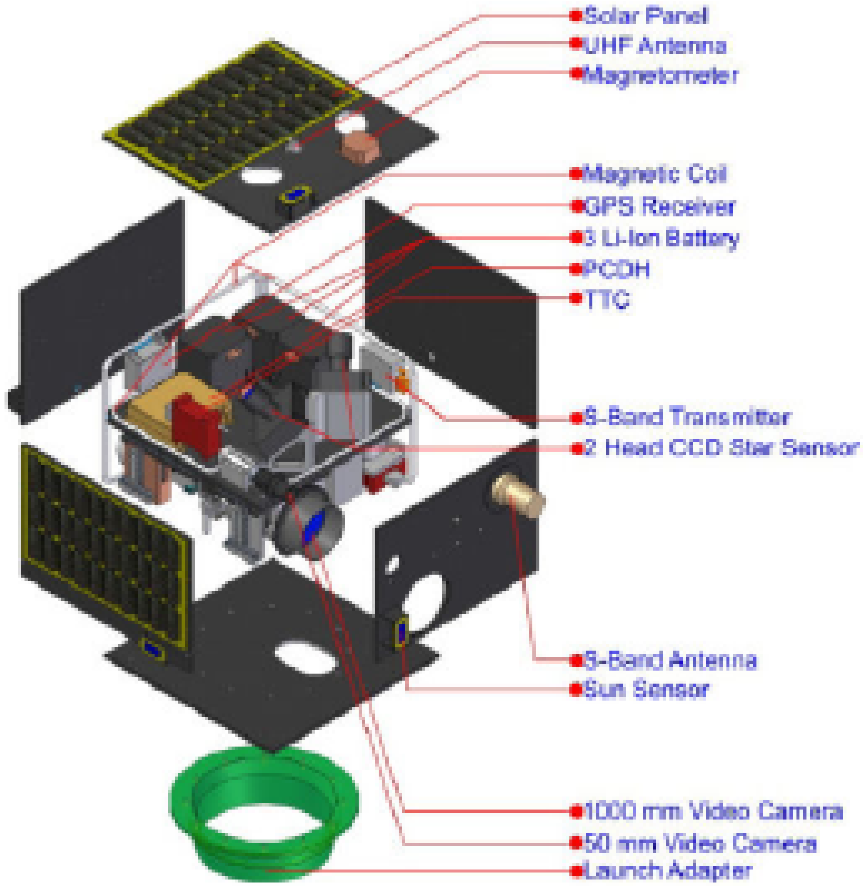
These are:

a. Twin LAPAN-ORARI Satellite with the following payloads: HDTV Video-camera, HDTV, video-camera LAPAN-TUBSAT, Ship Automatic Identification System, and ORARI Communication System for disaster mitigation. These satellites will be launched in the second half of 2012.

b. LAPAN-IPB micro-satellite for food security with the following payload: Imager for image resolution of 18 m with swath width 90 km and Automatic Identifiction System (AIS). Its launching is planned in 2013.

** Hardhienata, Soewarto, LAPAN, private communication, November 2011

LAPAN's next micro-satellite : Twin Satellites: LAPAN-A2 & LAPAN-ORARI



LAPAN-A2 and LAPAN-ORARI satellites developed based on the space proven LAPAN-TUBSAT satellite bus;

Both LAPAN-A2 and LAPAN-ORARI satellites are developed using same satellite bus and structure (twin satellites), with individual and complementary mission payloads.

LAPAN-A2 satellite payload: HDTV color video camera;

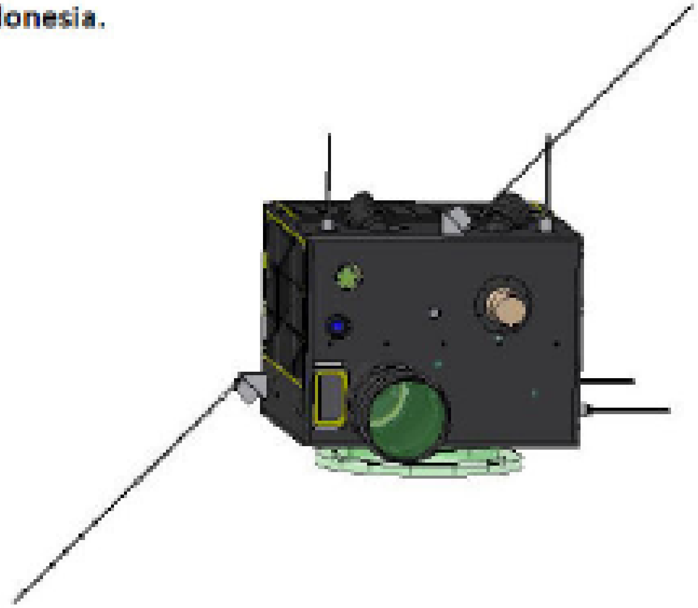
LAPAN-ORARI satellite payload:

1. 3-band multi-spectral imager
2. Amateur radio communication
   - Automatic Position Relay System (APRS);
   - Analog voice repeater.

LAPAN-ORARI Satellite Description

Primary Mission:
Support disaster management by amateur radio communication, as well as earth observation (multi-spectral remote sensing) for land use, natural resource and environment monitoring.

Objective: First satellite design, integration and test in Indonesia. Near equatorial earth orbit for obtaining more frequent daily satellite orbit overpass over Indonesia.



Orbit:
Near Equatorial LEO, at between 6 to 8 degree inclination and orbit altitude 650 km. Launch on second quarter 2011 (same as LAPAN-A2 satellite launch).

Payload:
Indonesian Amateur Radio Organization (ORARI) communication payloads:
1.Amateur radio Automatic Position Relay System (APRS) digital data communication relay.
2.Amateur radio analog voice communication relay.

Video camera PAL RGB for 80 km width coverage.

3 band multi-spectral imaging camera
Ground resolution: 24 m
Ground coverage: 154 km swath width
Band 1: 525 - 605 nm
Band 2: 630 - 690 nm
Band 3: 750 - 900 nm

Attitude Determination Instrument (ADI) laser beam beacon.

CONSIDERATIONS FOR FORMATION FLYING CONSTELLATION (1)

MIT has developed a spacecraft formation flying testbed which has been designed to provide a cost-effective, long duration, replenishable, and easily reconfigurable platform with representative dynamics for the development and validation of metrology, formation flying, and autonomy algorithms.[1]

The International Space Station (ISS) provides the ability for the creation of true laboratories in a microgravity environment. The availability of humans in the ISS presents a further advantage: the ability to put humans in the design loop. The MIT Space Systems Laboratory developed a new laboratory design philosophy to take advantage of these new resources.

The new philosophy is implemented in the SPHERES testbed, which creates a laboratory environment in the ISS that allows multiple scientists to develop and validate high-risk control, autonomy, and metrology algorithms for separated spacecraft that enable formation flight, rendezvous, and docking of satellites. [2]

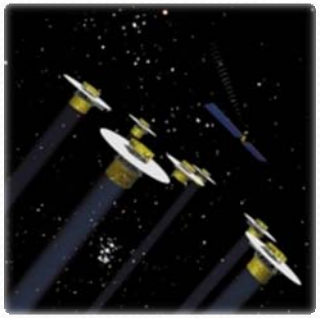
CONSIDERATIONS FOR FORMATION FLYING CONSTELLATION (2)

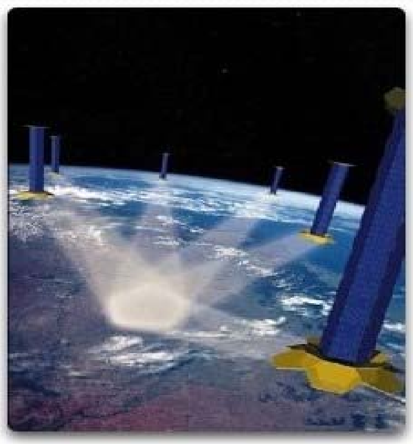
Consideration of Near-Earth Spacecraft Formation Flying for Tropical Environmental Monitoring is motivated by earlier efforts to introduce Tropical Earth Resources Satellite, and progress in a large host of operational satellites with similar missions and high-definition three-dimensional images.

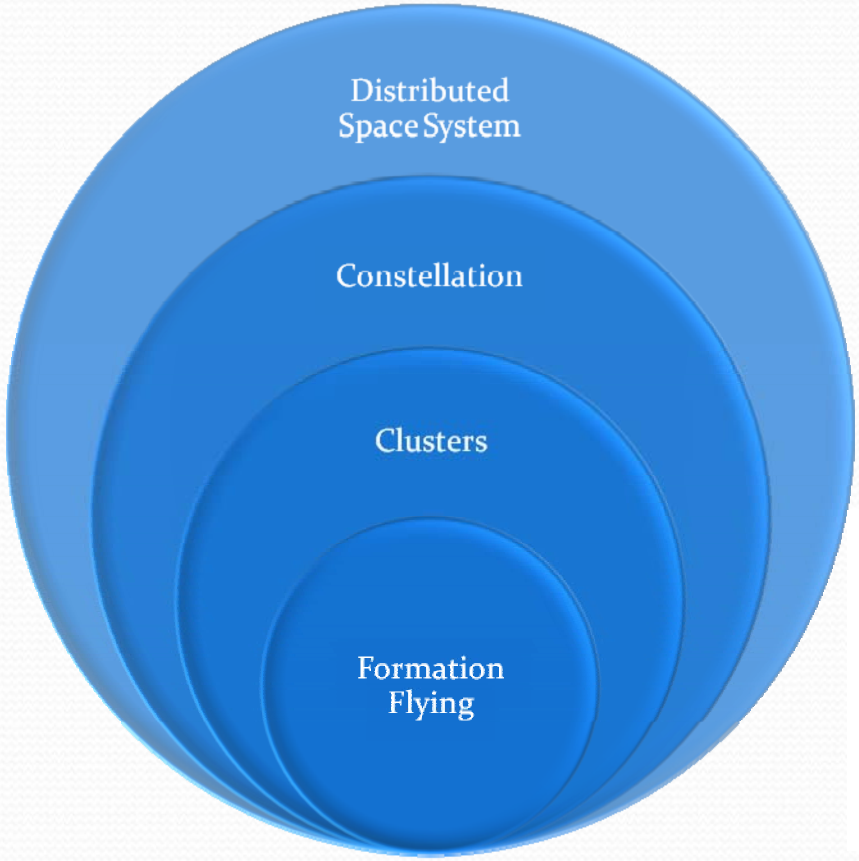
Starting from relative motion of multiple spacecrafts using Clohessy-Wiltshire Equation, a parametric study is carried out to obtain information on various Spacecraft Formation Flying configurations for near earth orbits of interest for such applications.

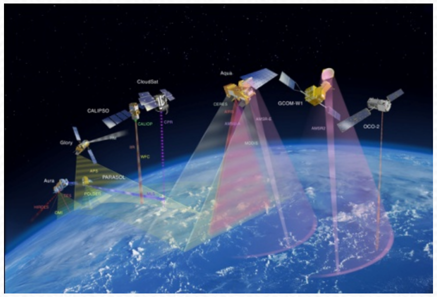
The work is concentrated on the review of the governing equations to produce spacecraft formation orbits and the resulting ground tracks beneficial for tropical environmental and resources monitoring. Parametric study to obtain relevant characteristics of these orbits is discussed.

SPACE FORMATION FLIGHT



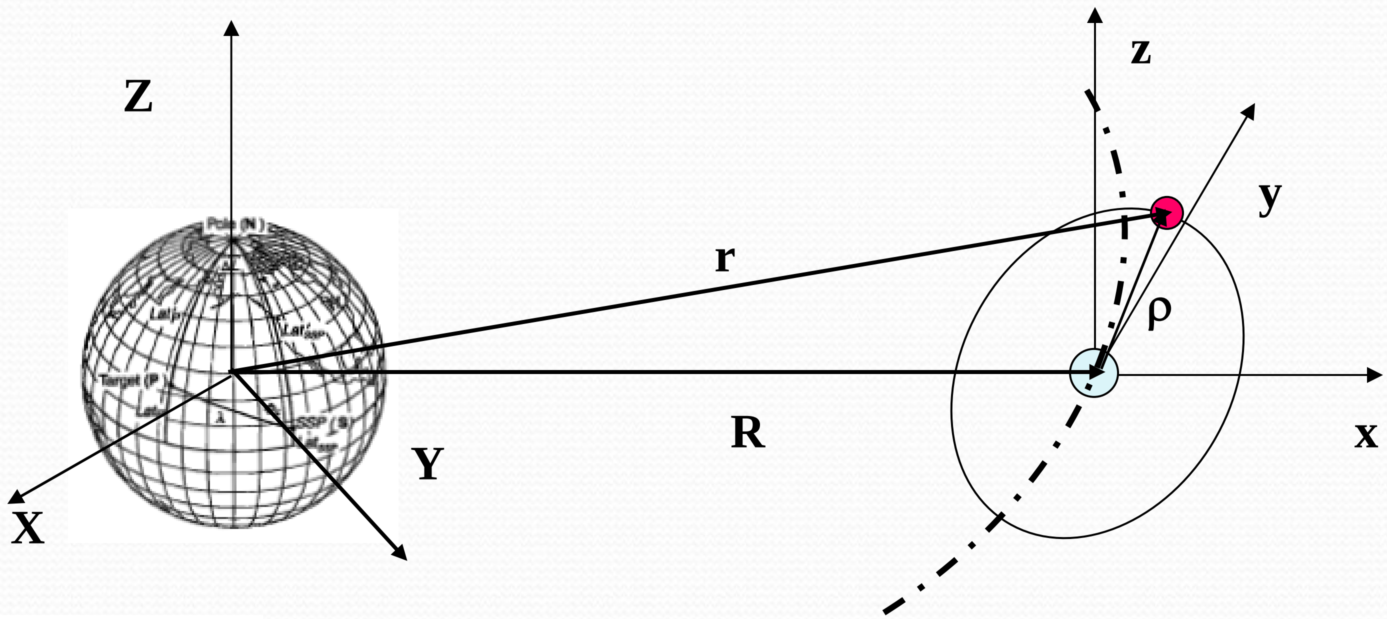






Formation Flying: A multiple-spacecraft system with desired position and/or orientation relative to each other or to a common target

RELATIVE MOTION DYNAMICS



$$\ddot{\boldsymbol{r}} = -\frac{\mu}{r^3}\boldsymbol{r}$$

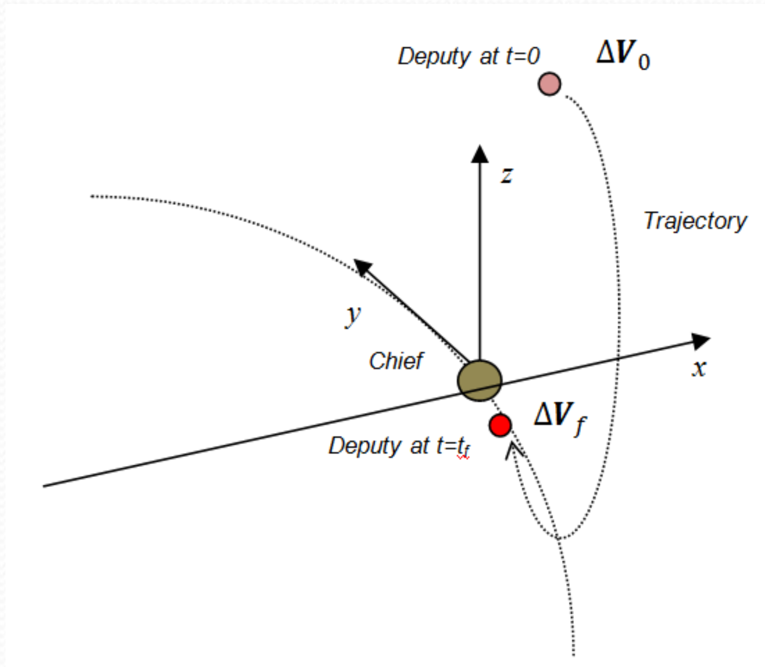
Newton's Law of Gravitation

$$\boldsymbol{r} = \boldsymbol{R} + \boldsymbol{\rho}$$

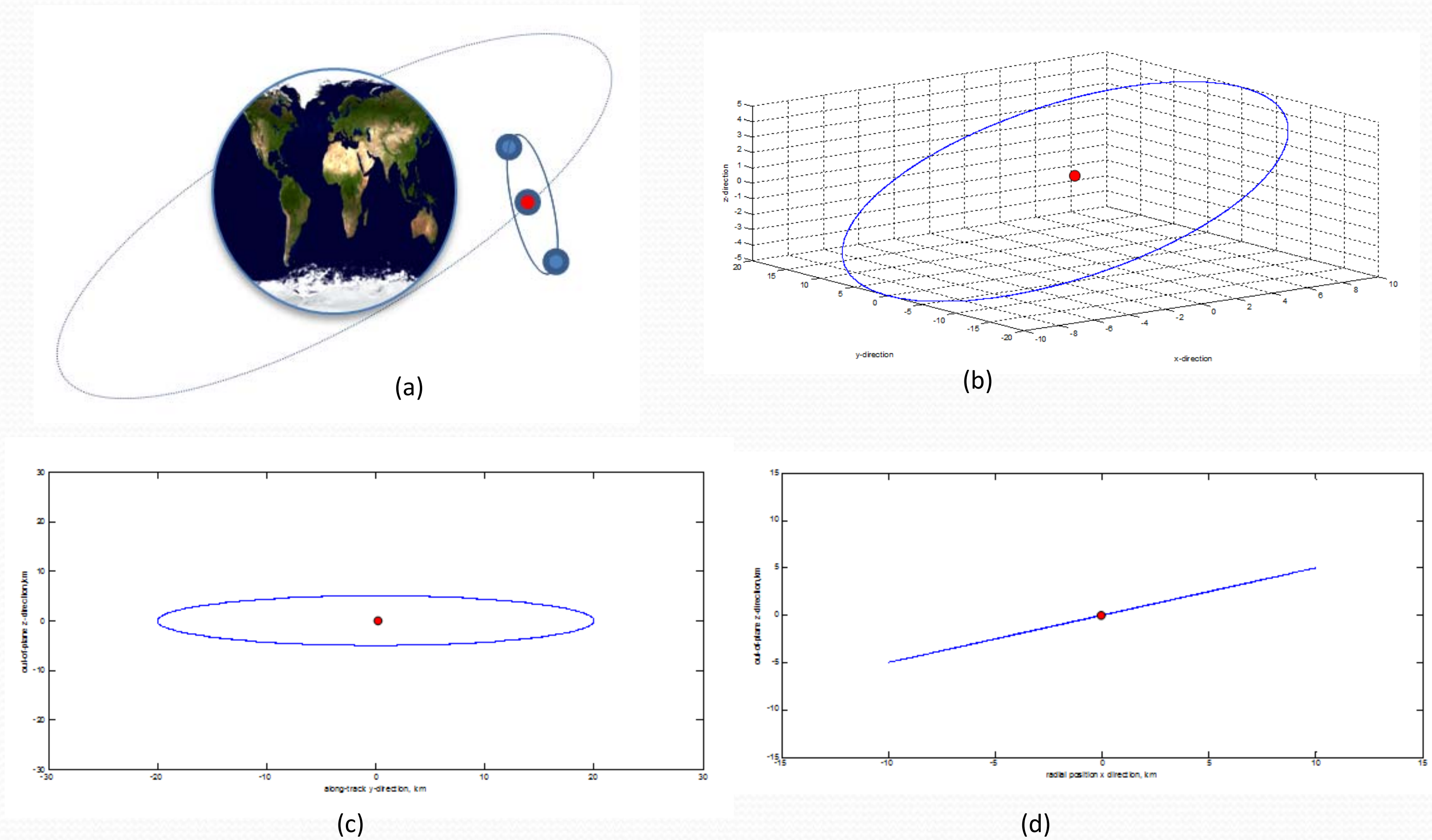
Position of *deputy* with respect *chief*

$$\ddot{\boldsymbol{\rho}} = -\frac{\mu(\boldsymbol{R}+\boldsymbol{\rho})}{\|R+\rho\|^3} + \frac{\mu}{R^3}\boldsymbol{R}$$

THE DELTA-V BUDGET FOR FORMATION FLYING MANEUVER



Maneuver of the *deputy* in the neighborhood of the *chief*



(a) Sketch of projected circular orbit in inertial frame (b)-(d) Illustration of the relative position of deputy satellite in relative frame centered on the chief satellite.

RELATIVE MOTION COMPUTATIONAL MODEL

$$\ddot{x} - 2\dot{\theta}_0\dot{y} - \ddot{\theta}_0 y - \dot{\theta}_0^2 x = -\frac{\mu(r_0+x)}{\left[(r_0+x)^2+y^2+z^2\right]^{\frac{3}{2}}} + \frac{\mu}{r_0^2}$$

$$\ddot{y} + 2\dot{\theta}_0\dot{x} + \ddot{\theta}_0 x - \dot{\theta}_0^2 y = -\frac{\mu y}{\left[(r_0+x)^2+y^2+z^2\right]^{\frac{3}{2}}}$$

$$\ddot{z} = -\frac{\mu z}{\left[(r_0+x)^2+y^2+z^2\right]^{\frac{3}{2}}}$$

$$\ddot{x} - 2n\dot{y} - 3n^2 x = 0$$

$$\ddot{y} + 2n\dot{x} = 0$$

$$\ddot{z} + n^2 z = 0$$

$$\ddot{x}'' = \frac{3}{k}\ddot{x} + 2\ddot{y}'$$

$$\ddot{y}'' = -2\ddot{x}'$$

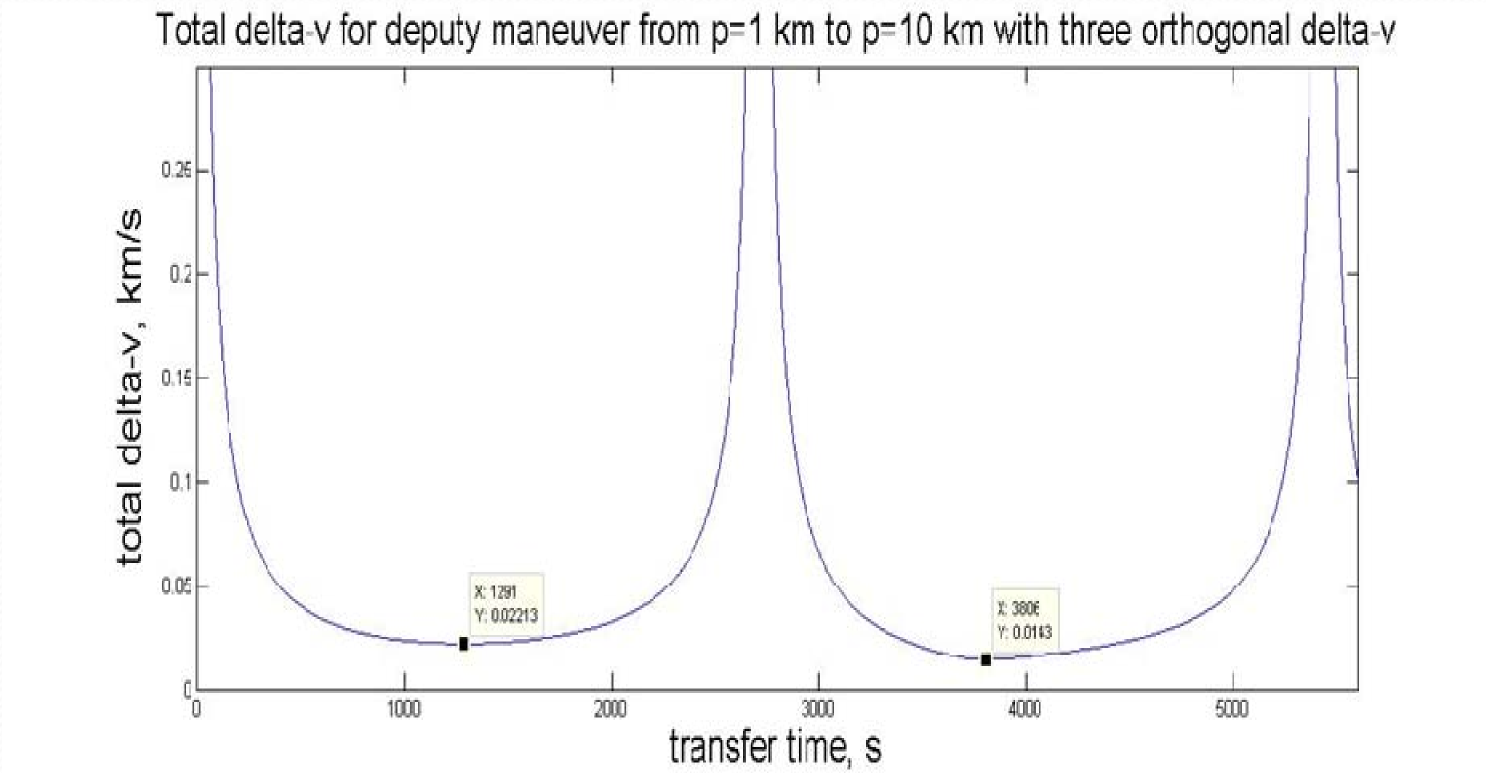
$$\ddot{z}'' = -\ddot{z}'$$

NONLINEAR MODEL

CLOHESSY-WILTSHIRE

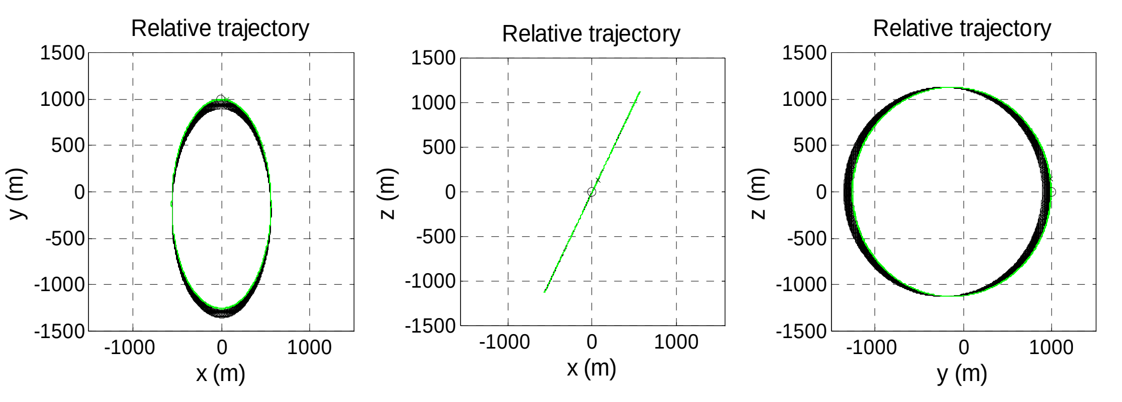
TSCHAUNER-HEMPEL

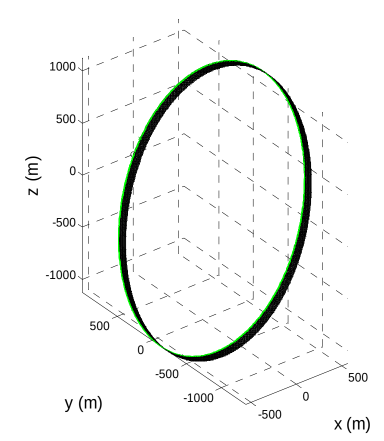
SAMPLE RESULTS



Δ-v for deputy satellite's maneuver from the initial and final positions as a function of the transfer time

SAMPLE RESULTS





Comparison of trajectories by CW model compared with the unperturbed nonlinear Keplerian motion considered in the study. The results shows that the model facilitate quick estimate for orbital design purposes.

FORMATION DESIGN FOR TROPICAL ENVIRONMENTAL MONITORING

Table 4

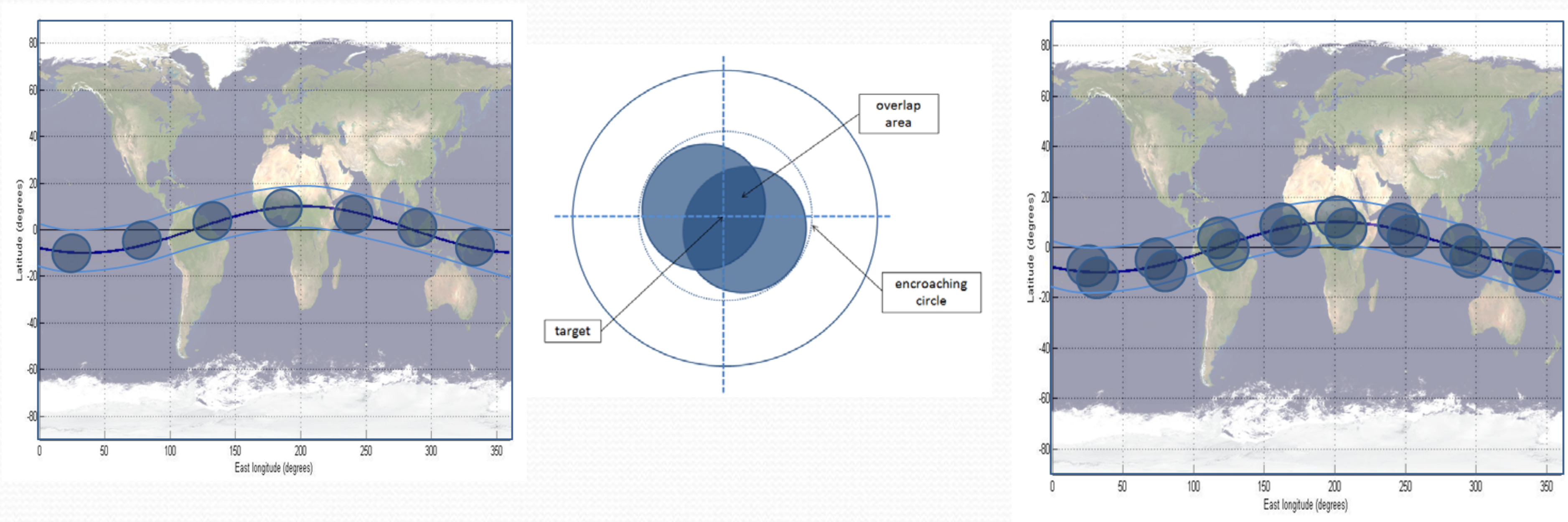
Principal Factors to be Considered for a Spacecraft Formation Flying Design designated for Tropical Environmental Monitoring, adapted from Reference 22.

Factor	Effect	Selection Criteria
Number of Satellites	Principal cost and coverage driver	More than one satellite to meet coverage, frequency of visits, swath width, etc
Orbital Parameters	Launch cost, Mission complexity and Coverage as effected by Constellation Pattern, Altitude, Inclination and Eccentricity	1. Select for best coverage between 15^0N-15^0S for tropical area 2. Low-Earth Orbit 3. Zero eccentricity for *chief* orbit only
Guidance and control Design	Formation guidance and control complexity	Should seek for simplified thrust control
Collision Avoidance Parameters	Preventing constellation/formation self-destruction	Carefully chosen type of formation, maximize the inter-satellite separation at plane crossings
Formation Configuration	Coverage performance	Select best coverage, revisit frequency, swath width, etc

ANALYSIS AND DISCUSSION ON GROUND-TRACK OF A LEO SPACECRAFT FORMATION AND REMOTE SENSING APPLICATIONS

- In order to provide an appropriate mechanism in analyzing and comparing the coverage of formation flying spacecraft, one can utilize a numerical simulation approach. Numerical simulations may be complex as they may consider satellite's observability, power and eclipse conditions, scheduling and ground stations. The simplest numerical approach for preliminary mission design purpose is the ground track plotting of the mission geometry. Ground track plot can show the overall coverage pattern of the mission geometry.

- The benefits of such ground track will be commensurate with application missions. For example, remote sensing missions for a group of countries in the tropical belt may require ground track coverage band along the equatorial line. For that purpose, one may reconstruct certain satellite orbital parameters to achieve desired ground track.



(a) Ground tracks of two satellites in LEO (847 km) circular orbit with 15º inclination and 180º angle of latitude separation for one orbital period for conceived TERS; (b) Circle encroaching Horizon (coverage) circles for Spacecraft Formation Flight; (c) Ground tracks for two deputy satellites with imaginary chief satellite including encroaching circle in the same orbit in (a) derived from the present philosophy.

CONCLUDING REMARKS

Within the perspective of a new United Nations Human Space Technology Initiatives, a comprehensive account is made to review past and ongoing activities in Indonesia related to space applications and technology of direct interest to human development, which could be well appreciated by non-space fairing communities.

The activities reviewed are focused on resources monitoring and disaster mitigation, human space technology activities as related to the benefits of micro-gravity environment to food, health and materials applications, and satellite technology development for enabling local capabilities in specific oriented needs as well as capacity building for future development.

Tropical Earth Resources Satellites and a large host of operational satellites with similar missions and high-definition three-dimensional images has been attractive for many equatorial countries.

Spacecraft Formation Flying is discussed within the above framework.

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3. Bunnik, N.J.J., van Konijnenburg, R. and Irsyam, M., *User Requirements for a Tropical Earth Resources Satellite (TERS) System*, NLR TR 84024 L, NIVR – LAPAN, Delft, 1984;
4. Kadri, T.M., Developing an Equatorial Earth Observation Satellite System, presented at COSPAR/IAF Symposium at the Forty-Fourth Session of UN COPUOS Scientific and Technical Subcommittee, Vienna, Austria, 12-23 February 2007.
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