Preliminary Design of Indonesian Military Surveilance Satellite

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Abstarct: Considering the fast area of Indonesia, its military will need platform with high coverage such as satellite to ensure proper observation of its defense territory. Therefore, the objective ofthe research is to make prelimiray design of satellite for Indonesian military surveillance operation. Since at the moment there are no special unit in Indonesian military dedicated for using satellite images insurveillance operation, the mission requirements are derived from the study of other countries military satellite, which is adjusted for Indonesian geographical conditions. The design assumes constraints on single LEO satellite and existing technology on optical payload. The design process yield a configuration of 1500 kg satellite with 3 deployable solar panels, orbiting at 700 km altitude and 10º inclination. Such platform could deliver image with best resolution of 1 m and 50 km swath, and, with maximum slew angle of 30º, the images can be repeated between 100 minutes to 24 hours, as requested in design requirements.
Key Words : Military Surveillance, Near-equatorial Satellite, Preliminary Design

Nomenclature

f : focal length
h : orbit height
d : CCD pixel size
X : image resolution
D : lens diameter
λ : wavelength
Q : quality factor for imaging

1. Research Backgrounds, Objectives, & Methods

Aeronautics & Astronautics is a study program under Faculty of Mechanical and Aerospace Engineering, ITB, which until now is the only one in Indonesia offering courses in orbital mechanics and satellite design and operation. Since 2011, it has developed amateur satellite groundstation for the teaching of satellite operation and research on orbit propagation modeling[1)]. The study program also performed research in satellite design, especially in attitude control of nano/pico satellite[2, 3)], and in the development of satellite simulator [4, 5)]. Based on that portofolio, in 2016, the study program is granted research assignment for designing satellite platform suitable for Indonesian military[6)].
Modern defense system rely heavily on C4ISR (Command and Control, Communications Computers, Intelligence, Surveillance, and Reconnaissance) for its effectiveness. Here, spatial information is one of the key element in the Intelligence, Surveillance, and Reconnaissance operation. For a nation with fast territory like Indonesia, such information can only be obtained efficiently using airborne and spaceborne platform. Such reason drive the objective of this research, which is to produce preliminary design for the satellite system dedicated for defense surveilance in Indonesia. The limitations of the design is that system has to be based on single satellite, and with the assumption exsiting space proven technology.
The standard method for performing satelite preliminary design is firstly performinguser requirements study, which then become the mission of the satellite[7)]. In this research, the user requirements are mostly taken from literature studies. The second step is to select the most appropriate orbit to serve the mission. In this phase, orbit dynamics/geometry simulations are performed, to measure the system performances and ensure its compliance to mission requirements. In aerospace system design, it is typical to perform literature study on the existing plaforms serving similar missions[7)]. The result from such study is baseline design parameters, that can be used to select the appropiate satellite launcher. The selection of launcher provide limitations for satellite payload and bus subsystem sizing, which are the last step in the preliminary design.

2. Mission Requirements

2.1. Military Surveilance Data Usage

Since Indonesia do not yet has military surveilance satellite, there are no special unit isdedicated to process satellite based images forreconaisance. The Navy Hidrology Services, the Army Topography Services, and the Air Force Aerial Photography Service are indicated to be the ocasional users of medium and high resolution satellite images provided by Indonesian Geospatial Information Agency[8,9].

Due to the limited information on Indonesian military user requirements for satellite imageries, the mission satellite requirements in this research will be derived from the references of other nations's military. References indicates that one of theobjective of military surveilance/reconaisance is detect strength, position, and readyness of military establishment/instalation, as in Fig. 2.1.1. Here, the images has to have enough details so that the type of the military vehicles can be identified[10].

Fig. 2.1.1. Observation of military facilities from reconaisance satellite[10]

Another military mission using satellite imageries is to observe the object to be attacked, and analize the damage from the attack. Fig. 2.1.2 shows case for planning and damage assesment of air strikes on 2 loactions in Bagdad in 2003, using satellite with image resolution of 50 cm[11].

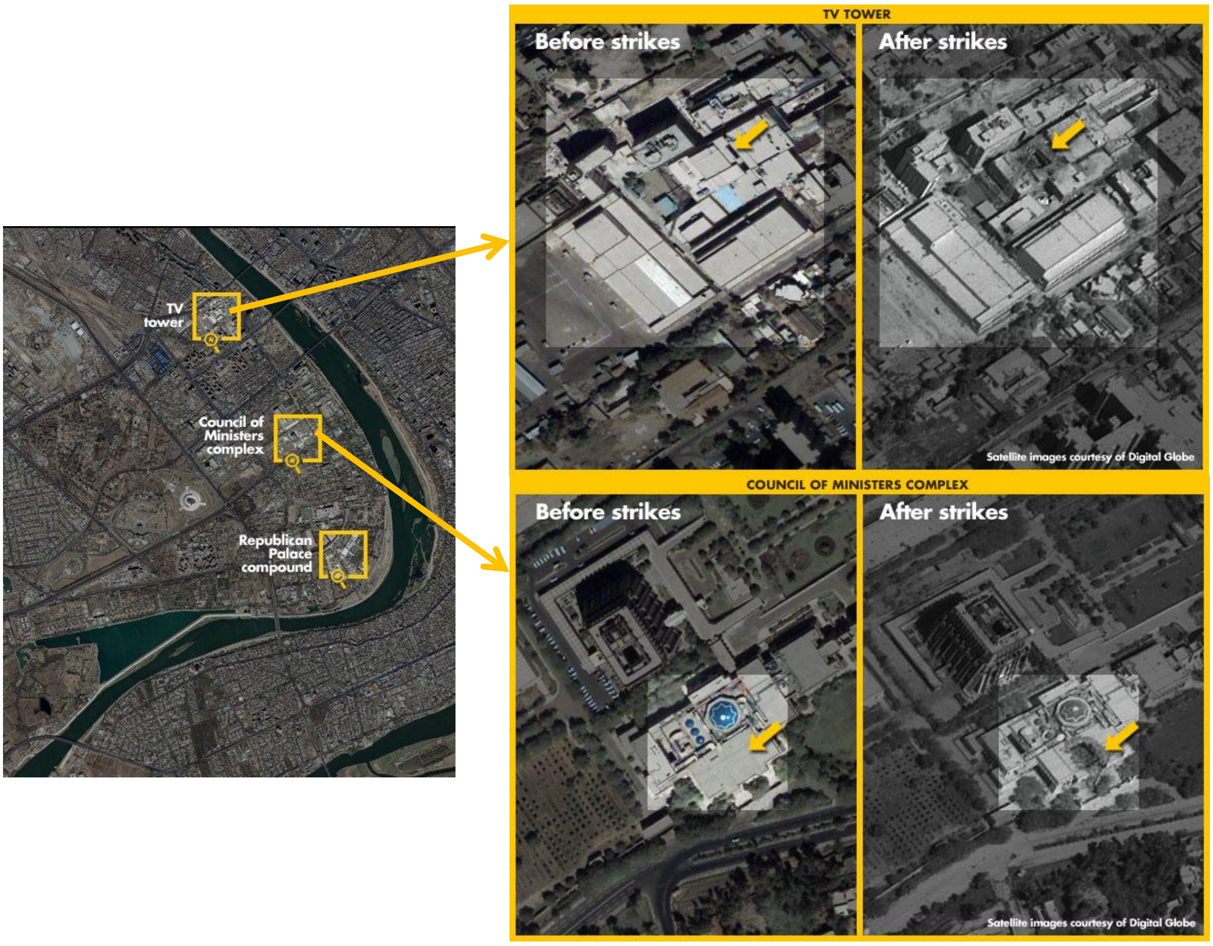

Fig. 2.1.2. US military damage assesment mission in Bagdad in 2003 using Worldview satellite[11)]

2.2. Military Surveilance Satellites Comparison

Table 2.2.1 shows data of military surveilance satellites, compiled from references [11–16)]. The data shows that optical satellite used for military surveilance has less 1 m resolution. As in subchapter 2.1. the smaller resolution will ensure the ability to recoqnize type of military vehicle, or determine the damage from sirstrike.Meanwhile for SAR (synthetic aperture radar) satellite, the image has resolution of 1-5 m. The advantages of SAR satellite is ability to take image during night and could penetrate cloud. Such advatages is valuable for military operations, since they should not be limited by time of day and weather.
Another performance parameters of military surveilance satellite is its repeat rate (time needed to produce the image of same place). The mission demand, such as detecting the movement of military asets or damage assesment from airstrike, require as small repeat time as possible. Unfortunately, pursuit of the other desired satellite parameter, i.e. image resolution, is in contrary to the direction for best repeat time. Pleiades system use constelation of 2 satellites in order to get 1 day repeat time. SAR-LUPE uses constelation of 3 satellites to get repeat rate less than 24 hours.
Since the military surveilance missions in chapter 2.1 use images from satellite with optical payload, the satellite design in this research is limited to optical payload. Therefore, the required resolution is 1 m. Image swath is a function of pixel numbers in the satellite’s line imagers. In Worldview satellite, the image swath is more 40000 times the image resolution, which means technology available for line imagers with more than 40000 pixels. Asumming the camera technology is keep advancing, the design assumes that the satellite camera will use imager with 50000 pixels, or the image swath will be 50 km

Table 2.2.1. Military Surveilance Satellites

Satellite	Owner	Orbit height (km)	Orbit inclination (deg)	Weight (kg)	Resolution (m)	Swath (km)	Repeat (days)	Payload
KENNEN	USA	260 x 1007	97.9	13607	0.15-0.09	-	4	Optic
Worldview-3	USA	617	98	2800	0,3	13	-	Optic
Pleiades	France	694	98.2	970	0,7	20	1	Optic
YAOGAN 4	China	652 x 634	97.92	500-1000	1-3	20-30	-	Optic
YAOGAN23	China	513 x 492	97.33	500-1000	-	-	-	SAR
SAR-LUPE	Germany	468 x 505	98.18	770	0.5	5.5	<1	SAR
Kondor-E	Russia	500	74.75	1150	1-5	10/20/150	2-3	SAR
IGS-4B	Japan	486-491	97.3	850	1-3	-	-	SAR

3. Satellite System Design

3.1. Orbit Selection

Table 3.1.1. show that majority of satellite uses orbit height between 500 to 700 km. Only KENNEN use highly eliptical orbit, to achieve very high resolution image when taken at its perigee. Reference[12)] also indicated that such system in longer in operation since 2013.

Since the area of interest for Indonesian military is only in Southeast Asia region, between 10° N to 10° S, the orbit selected will be LEO with low inclination. Such orbit could pass Indonesian teritory 14 times per day, and therefore could ensure smaller repeat rate. Such orbit also has been applied by 3 Earth observation satellites of Southeast Asian nations, i.e. Indonesia's LAPAN-A2/ORARI [17)], Malaysia's Razaksat [18)] and Singapore's Teleos-1[19)].

Based on the above references, satellite operation simulation is perfomed using free lisenceSTK (Satellite Tools Kit) software. Several iterations are performed using orbit altitude between 500 to 700 km, and inclination betwen 8 to 10 degree. The best orbital parameters for repeat rate performance parameters are shown in table 3.1.1.

Table 3.1.1. Best orbit parameter for repeat rate performance

Orbit height (km)	700
Orbit inklination (deg)	10
Image swath (km)	50
Max. Slew angle (deg)	30

Fig. 3.1.1 shows the orbit geometry for such parameters. With asumption that the satellite could slew until 30 degree (left & right), the potential area that can be covered (lateral to flight direction) is 800 km. Such coverage ensure that the satellite could take an image of any place in Indonesia (including South China sea and Norrth Australian waters) daily. The area located between 2 passes ground track (yellow lines)can be observed within 100 minutes, as shown in Fig. 3.1.1.

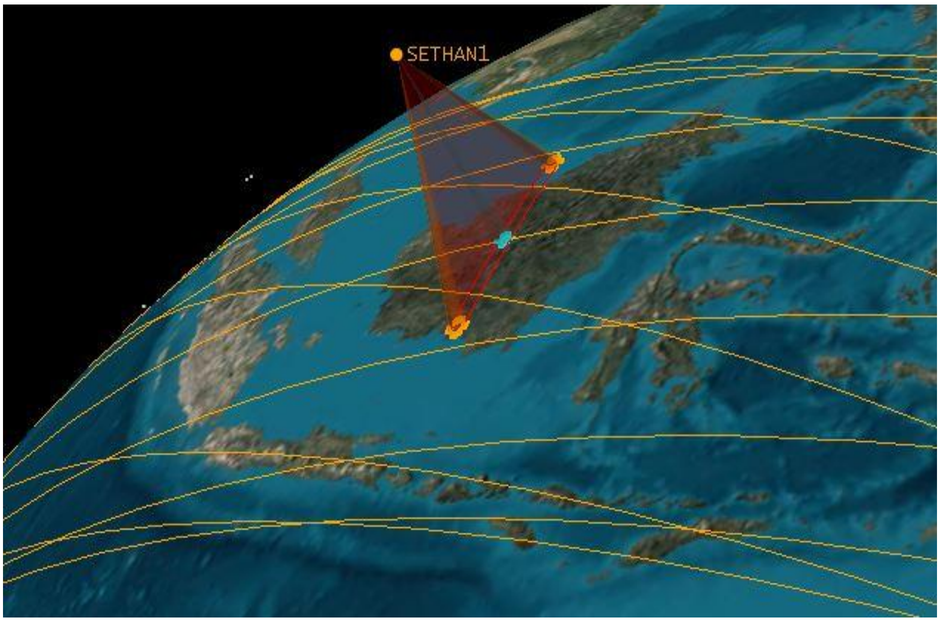

Fig 3.1.1. Orbit geometry showing coverage for 30 deg slew angle

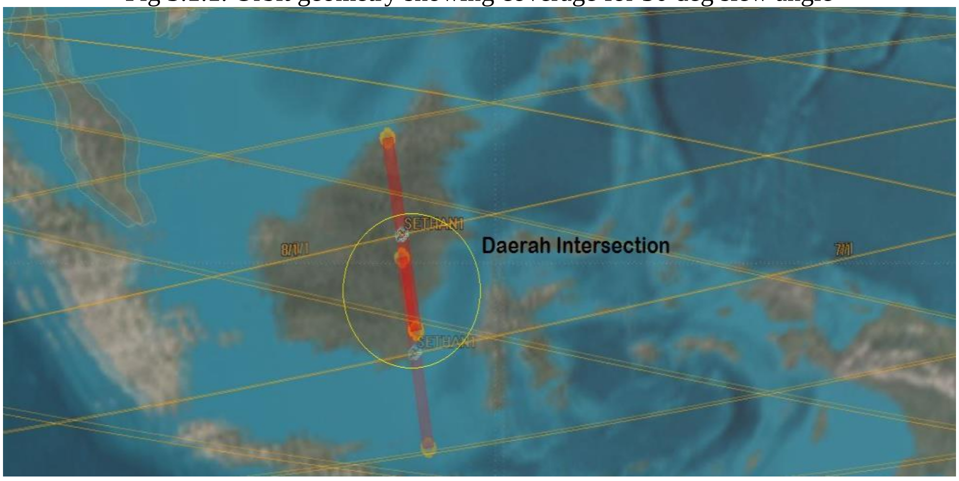

Fig 3.1.2. Common scan area between 2 passes

3.2. Launcher Selections

Table 3.2.1. LEO launcher capacity [20,21)]

	PSLV	Vega	LongMarch-2C
Fairing diameter (m)	3,2	2,6	3,35
Fairing length (m)	8,3	7,8	8,1
Payload capacity at LEO (kg)	1500	1500	1400

From study at chapter 2.2, it can be concluded that considering weigth design margin, the typical 1 m resolution is between 700-1200 kg. Combined with conclusion from chapter 2.1, where the orbit height is 700 km (LEO), make the selection of satellite launchers limited to 3 choices shown in table 3.2.1 Using the launchers' data, the satellite size at launch configuration should not exceed the diameter of 3 m and length of 8 m.

4. Subsistem and System Sizing

4.1. Payload Sizing

Satellite's optical payload typically consist of lenses, CCDs (with associated filters), and processing computers. The design of lens is governed by Eq. (1) and (2). The design assumed that the common

CCD used for space application, which pixel size is 9 µm. Based on Eq. (1), at orbit height of 700 km, the focal length needed to produce image of 1 m resolution is 6,3 m.

$$f = \frac{h\,d}{X} \quad (1.)$$

Eq. (2) based on the light diffraction theory, which ensure the image quality will be high. Based on the equation, for focal length of 6,3 m and pixel size of 9 µm, the lens diameter needed is 1,76 m.

$$D = \frac{2.44\,\lambda\,f\,Q}{d} \quad (2.)$$

To optimize the use of space in the satellite, Cassegrain (mirror-type) lens is used. Therefore, the actual length of the lens is 2.1 m.
Reference[16)] show that optical payload of such performance may consume 400 watt of power, and has weight of 195 kg.

4.2. Satellite Bus Sizing

The satellite bus consists of all components used to support the payload operation. For the case of Earth observation mission, the payload will needs electrical power, setting/calibration support, stable and accurate pointing, and data transmision system to sent the image to groundstation. The satellite bus will carry S-band TTC, main computer, X-band data transmision system, Li-ion bateries, GaAs solar panels, structure that also serve as pasive thermal control, and attitude control system that consist of control moment gyro, 2 star sensors, a Sun sensor, magnetometer, and magneto-torquers. The satellite does not carry propulsion system since local time maintenance operation is not needed for satellite at near equatorial orbit.In this satellite bus design, power consumption of the subsystems/components are mainly taken from reference[7,16)]. The result is satellite consumption of 273 W.
Combined with the payload power consumption, total satellite power consumption is 673 W when imaging (50% of time). Therefore, per-orbit power consumption is 788 Whr. Such budget has to be supplied by the satellite power generator, which has 3 deployable solar panels with dimension 1x2,3 m placed at anti-nadir direction (see fig. 4.1), assuming camera axis is always pointed close to nadir. For satellite with such configuration at near equatorial orbit, the solar panel not always pointed straight to the Sun. Calculation yield that the per-orbit power production capacity at end of life (5 years) is 812,5 Whr. This means that the design is feasible, i.e. the power production capacity is higher than power consumption needed for satellite operation.
Based on the lens design in chapter 4.1 and the solar panels design above, the satellite configuration is drawn as in Fig. 4.2.1. During the launch, the solar panels will be folded so the satellite can be fitted into simulated LEO launcher fairing envelope.

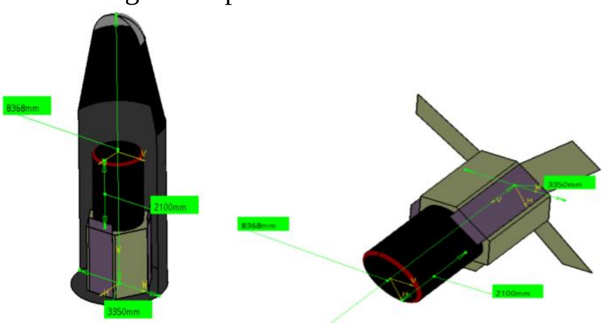

Fig 4.2.1. Satellite at launch (inside simulated fairing) and deployed configuration

5. Conclusions and Recommendations

This research has fullfil its objective of performing preliminary design for Indonesian military satellite. The satellite system parameters are:

Orbit height	700 km
Orbit inclination	10 deg
Image resolution	1 m
Image swath	50 km
Max. slew angle	30 deg
Reapeat rate	100 minutes to 24 hours
Satellite weight	No more than 1200 kg
Satellite diam. Envelope	3 m
Satellite height	4,4 m
Lens length x diameter	2,1 x 1,76 m
Solar panels	3 x 1 x 2,3 m
Max. power consumptions	788 Whr per-orbit
Power prod. capacity (EOL)	812,5 Whr per-orbit

Should the satellite to be procured from international supplier. The data can be used to make cost estimate of the project, and to find appropiate supplier.
Should the satellite is to be made in Indonesia, the data can be used to start component procurements and detail design. Another alternative is that the design can be optimized further to consider civilian remote sensing missions, or to upgrade it into a dual- used, military-civilian Earth observation satellite. Such scenario will addnumbers of stakeholders that will support the program.

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