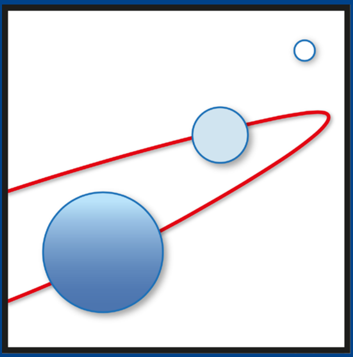

Research on Unidentified Aerial Phenomena

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Malte Reitemeyer,
Felix Weinmann

Detection of UAP with a Nano Satellite

Nr. 1

Research on UAP

In der Schriftenreihe „Research on Unidentified Aerial Phenomena“ erscheinen Beiträge zu neuen Entwicklungen aus dem Bereich der Forschung zu Unidentified Aerial Phenomena. Diese können sehr gute studentische Arbeiten, Dissertationen, Aufsätze zu relevanten Themen oder Ergebnisse von Projektarbeiten beinhalten.

Herausgeber:
Prof. Dr.-Ing. Hakan Kayal

Julius-Maximilians-Universität Würzburg
Prof. Dr.-Ing. Hakan Kayal
Professur für Raumfahrttechnik
Informatik VIII
Universität Würzburg
Emil-Fischer-Str. 32
D-97074 Würzburg
Tel.: +49-931-31-86649
Fax: +49-931-31-81368
hakan.kayal@uni-wuerzburg.de

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Universitätsbibliothek Würzburg
Am Hubland
D-97074 Würzburg
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Prof. Dr. –Ing. Hakan Kayal
Professur für Raumfahrttechnik
Informatik VIII

Detection of UAP with a Nano Satellite

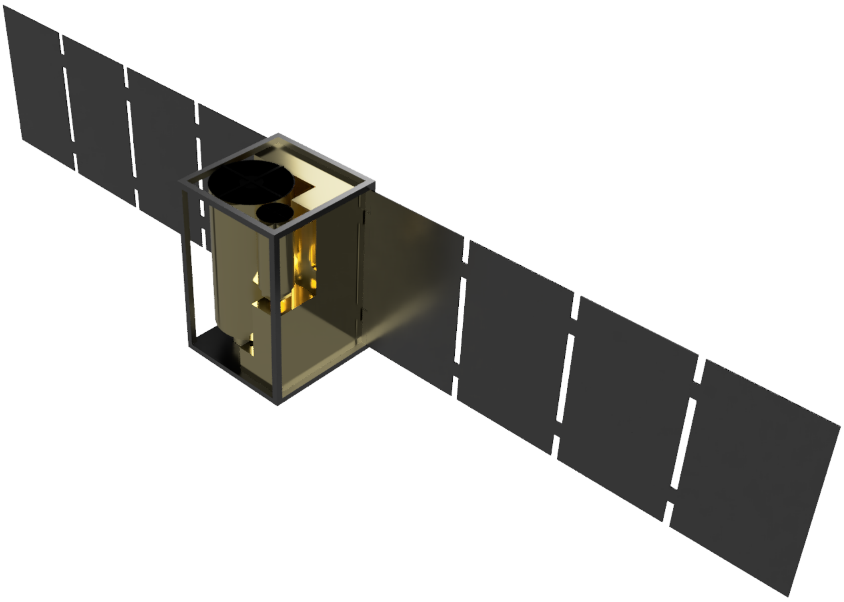
A feasibility study

by

Malte Reitemeyer and Felix Weinmann

supervised by

Prof. Dr.-Ing. Hakan Kayal



February 24, 2022

Report of the semester project Spacecraft System Design

Continued reports over the past decades of unknown aerial phenomena (short UAP) have given high relevance to the investigation and research of these. Especially reports by US Navy pilots and official investigations by the US Office of the director of national intelligence [1] have emphasized the value of such efforts. Due to the inherently limited scope of earth based observations, a satellite based instrument for detection of such phenomena may prove especially useful. This paper as such investigates the possible viability of such an instrument on a nano satellite mission.

Contents

List of Figures

List of Abbrevations

CCD	**C**harge **C**oupled **D**evice
CMOS	**C**omplementary **M**etal **O**xide **S**emiconductor
EMR	**E**lectro-**M**agnetic **R**adiation
NIR	**N**ear-**I**nfra**R**ed
ODNI	**O**ffice of the **D**irector of **N**ational **I**ntelligence
Radar	**Ra**dio **d**etection **a**nd **r**anging
SAR	**S**ynthetic **A**pature **R**adar
UAP	**U**nidentified **A**erial **P**henomena
UFO	**U**nidentified **F**lying **O**bject

1 Background and Motivation

Unidentified aerial phenomena (UAP) is a general term for aerial observations that can not be explained by known objects or events. Reports of such have been common for many decades and some can be found in historical records from many centuries ago. Scientific data of sufficient reliability and quantity however is scarce. As these may present opportunities to investigate gaps in our understanding of atmospheric events or other scientific fields, a more thorough understanding of their properties and nature could prove highly useful. However, after the so called „Condon Report“[2] in 1968, nearly all scientific research of unidentified aerial phenomena seized. It concluded that the study of UAP, then more commonly known as unidentified flying objects (UFO), has brought no scientific value and is unlikely to do so in the future. This conclusion has been challenged by other researchers since then.

Due to the recent report of the United States of America's director of national intelligence [1], scientific research and interest in UAP has resurged. This includes ongoing research efforts for UAP in Germany since 2008 at the interdisciplinary research center for extraterrestrial studies[3] with completed projects like RTSP-Observation[**rtsp**] and current projects like SONATE-2[22] and SkyCAM-5[4]. One of the biggest problems of UAP research is the relative lack of systematic data collection about UAP, as most data is gathered coincidentally. This reduces reliability and introduces biases, overall hindering the scientific analysis aiming at a more sophisticated categorization. A central limitation of all current systematic UAP data gathering, such as skycams [4], is their ground based operation. Vastly more expansive data sets could be produced by a satellite mission for searching UAP. Such ideas have been previously proposed, though these efforts are still ongoing [5]. Current satellites have shown the earth observation capability required but are missing the required algorithms for UAP detection. In particular, a feasibility analysis of the observation of UAP using a nano satellite architecture has become more relevant with the recent growth of nano satellites and their potential for global coverage.

2 Mission statement

Study of a payload for detection of UAP on a nano satellite. Drafting of a technology demonstrator for the detection of UAP on a satellite platform. This is constrained within a nano satellite framework of 27u or smaller. The choice of detection method is likely to align with known UAP characteristics.

2.1 Goals

1. Localization of UAP
2. Determination of phenomena characteristics
3. Statistical analysis of UAP appearances

2.1.1 Localization of UAP

For any further analysis, the detection and localization of UAP is required. The payload should be capable of detecting most UAP appearances and determine their locations from orbit.

2.1.2 Determination of phenomena characteristics

As further described in chapter 3, only few sources provide quantifiable information about UAP. The payload should be capable of providing additional quantifiable data about the UAP beyond the information about the existence of the UAP.

2.1.3 Statistical analysis of UAP appearances

Current UAP reports tend to cluster around positions with focused observers like U.S. air force training grounds [1]. A satellite is capable of global coverage and provides therefore the only possibility to measure UAP appearance locations without observation bias. The payload should therefore be capable of providing data usable for global statistical analysis of UAP appearances.

2.2 Payload constraints

1. The payload has to fit into a 30U nano satellite. This constraint arises from the mission statement.
2. The orbit is a 500 km circular sun-synchronous orbit.

2.3 User requirements

1. UAP detection
2. UAP localization
3. Detection reliability
4. Known phenomena
5. Additional information

2.3.1 UAP detection

The payload needs the capability to detect UAP in one of the following spectral bands to be able to fulfill the goal described in section 2.1.1.

- Microwave/Radio
- Visible
- Infrared

2.3.2 UAP localization

The payload needs the capability to localize UAP in time and space to fulfill the goal described in section 2.1.1.

2.3.3 Detection reliability

The payload is required to have a high detection reliability under similar circumstances to allow meaningful statistical analysis (section 2.1.3). Therefore it has to be capable of detecting a predetermined subset of all UAP occurrences with a known certainty.

2.3.4 Known phenomena

The payload needs the ability to differentiate between UAP and known phenomena to be able to detect UAP (section 2.1.1).

2.3.5 Additional information

The payload needs to provide additional information about the UAP in one of the following ways to provide data beyond the existence of the UAP (section 2.1.2).

- Spectroscopic analysis
- High resolution imaging
- Movement analysis

3 UAP Characteristics

In this chapter, observed and distinctive behavior and appearance of UAP is analyzed. Characteristics not observable with satellites, like sound, are not included. Due to the large number of as unidentified reported identified or (with more data) likely identifiable aerial phenomena, this analysis uses only data with multiple independent sightings and sufficient available data to exclude a known phenomena. Determining UAP characteristics is hindered due to the large number of reports focusing on proving the existence of UAP without providing quantifiable descriptions of the observed phenomena.

3.1 Shape and size

The COMETA report[6] contains descriptions of several varying UAP shapes and sizes:

- Sphere with one to two meters in diameter
- UAP changing its shape between a bell and a lens
- A disk with 100 to 200 meter diameter
- Ball with 40 meter diameter and separating lens shaped object
- 20 meter diameter saucers with seven meter thickness
- Four to five meter diameter disk with hemispherical dome mounted

Due to the massively varying shapes and sizes, this feature is not distinct enough and can therefore not be used to reliably identify a UAP from orbit. The small size of 1 meter diameter in some of the UAP reports implies the necessity of an equally small ground sampling distance for detection and analysis.

3.2 Movement

Various movement characteristics are described in the COMETA report [6]:

- Supersonic movement and high maneuverability like military aircraft
- Sudden disappearance
- An UAP with speeds between 3200 - 6400 km/h
- Sudden movement from immobility to 600 - 950 km/h

- Sudden movement changes with line segments of 13 - 30 km and abrupt stops 3 - 6 min in between
- “Extraordinary degree” of maneuverability
- Seemingly lacking inertia, “outstanding” maneuverability, two to three times the speed of modern combat aircraft (1990), hovering above the ground at times
- Temporarily following airplane
- Estimated speed of 3000 km/h
- Slight oscillations, stationary, moving away with very high speed
- Jerky movements, abrupt starts and stops, escape at “lightning speed” (supersonic)

The preliminary assessment of the U.S. office of national intelligence [1] reports UAP movements stationary in winds aloft, moving against the wind, displaying abrupt maneuvers and moving at considerable speeds without discernible means of propulsion. A paper analyzing the flight characteristics [7] reports minimal UAP accelerations from 68 g to 5370 g with an speed estimation up to Mach 60 (around 20 km/s).

From the data[7] we assume that the maximal velocity of a UAP is 20 km/s. The unique movement and acceleration characteristics provide a feature usable for UAP identification.

3.3 Location of appearances

It is assumed that all observed clustering of UAP sighting locations may be a result from observation bias[1]. We will therefore only analyze the flying height due to its importance in determining the required capabilities of the sensor.

The COMETA report [6] contains reports with vastly varying flying heights. Some UAP appearance were flying low above the ground (20 - 100 m above ground) with other UAP flying at heights up to 7000 m. In [7], the analyzed UAP sightings contain a sighting coming from low earth orbit (detected by missile defense radar) before coming in sight of a naval radar system at around 24 400 m.

We conclude that constraining the geographic coordinates of appearances is not possible due to insufficient observation coverage and assumed observation bias. Since multiple observers are recommended for UAP confirmations, we will consider 25 km above sea level as an upper bound.

3.4 Characteristics in the optical spectrum

The COMETA report [6] features optically differing UAP:

- During daytime:
    - Non glowing chestnut brown object
    - Intense blueish-light
    - Large red light
    - Non-glowing metallic gray object
    - Green ball
- During nighttime:
    - “Very bright” glowing UAP
    - Pulsating bluish white light, middle red light circle, color changing
    - White glowing sphere with green glowing comet tail
    - Brightly lit dome
    - Two flashing lights at the side

Various different behaviors in the optical spectrum are shown. Many appearances share a constant light emitting property, during nighttime nearly only glowing UAP are reported. This property can therefore be used for UAP detection. Observed color differs between UAP reports and cannot be used for detection.

3.5 Characteristics in the microwave spectrum

In the COMETA report [6], multiple sightings could explicitly not be found under radar. Others however, leave various traces in the microwave spectrum:

- 50 s track on radar
- Tracks on multiple radar systems
- Pulsating microwave source
- Interruption of surrounding electronic grids

The ODNI assessment [1] indicates appearance of many UAP on radar sensors.

The characteristics in the microwave spectrum varies between no signature to active disturbance of electronic equipment. Therefore only a subset of all UAP appearances can be detected in the microwave spectrum.

4 Selection of detection methods

For the purpose of a broader, more general selection of a detection method, the possibilities are split into active and passive electromagnetic radiation, and others. Active and passive electromagnetic radiation, further referred to as EMR, are further categorized by the wavelength used.

4.1 Electromagnetic radiation

Due to atmospheric absorption and scattering, only certain bands of the electromagnetic spectrum are usable for observation. This excludes ultraviolet light and shorter wavelengths, as well as wavelengths longer than about 10 m. 20 µm to 1 mm are also not viable due to atmospheric absorption. The radio wavelengths between 1 mm and 10 m are largely available, as well as visible light and near-infrared. Wavelengths of thermal infrared from 5 to 20 µm are fully transmitted, while the remaining mid- and long-wave infrared contains many individual absorption lines, making transmission inconsistent.
This leaves three main frequency bands of investigation: Visual/NIR, thermal IR and radio.

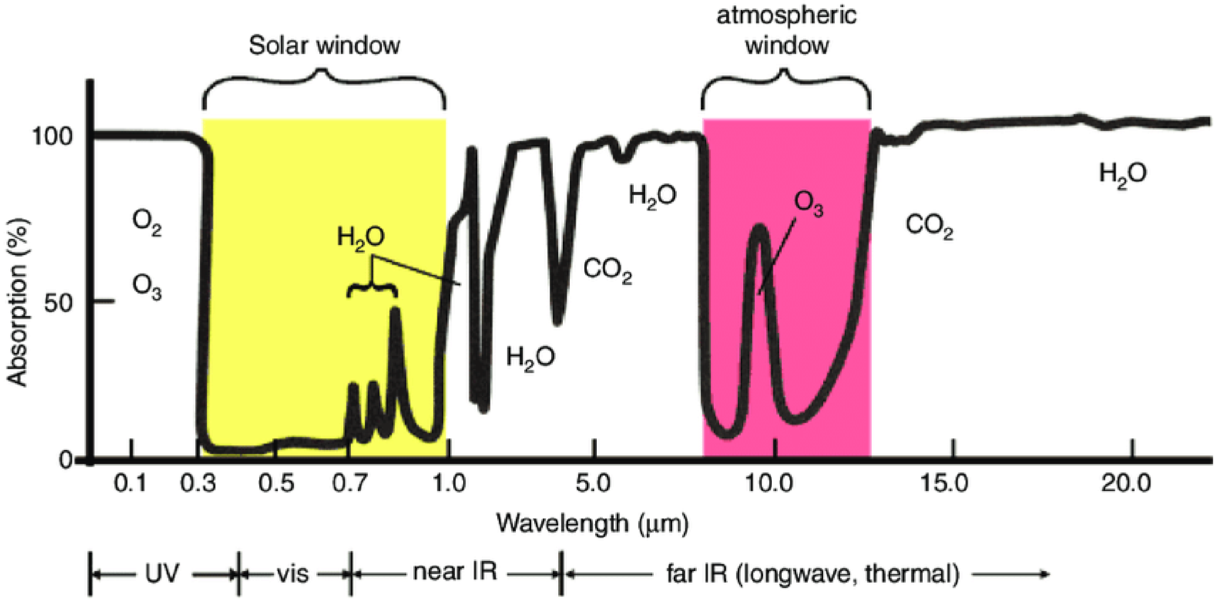


Figure 4.1: Characteristic atmospheric absorption of wavelengths between 0.1 and 20 µm, attributed to the respective molecules [8]

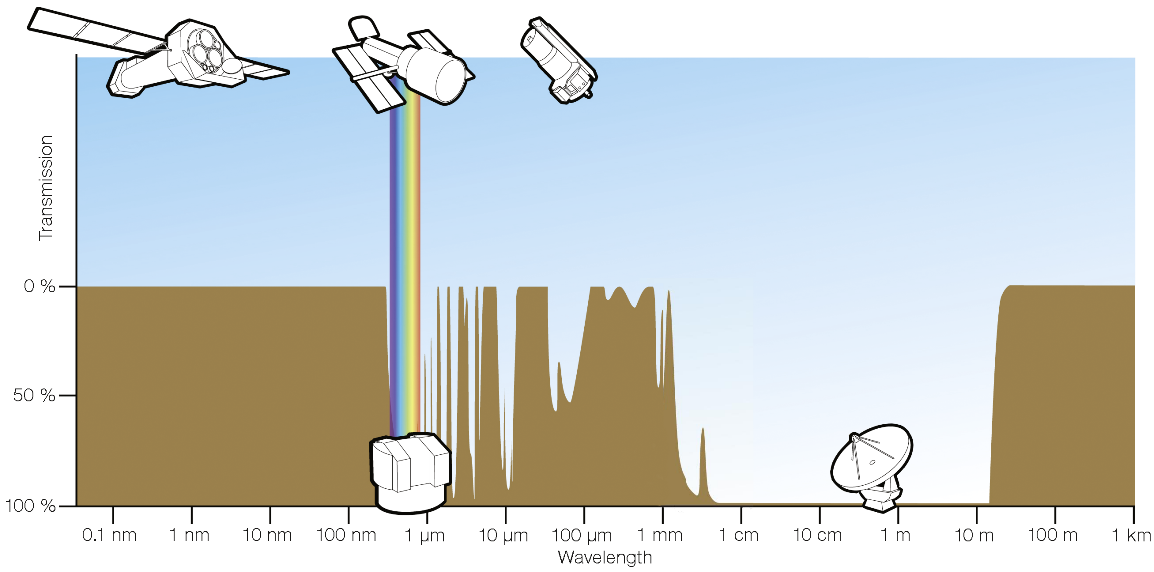


Figure 4.2: Broad range atmospheric transmission of wavelengths between 0.1 nm and 1 km, showing visual, infrared and radio window [9]

4.2 Active EMR

Active methods carry the inherent limitation of power requirements for the emission. These are primarily affected by three parameters, being the distance to the target, the size of the target area, and the desired illumination power per area. The distance is set by the mission description, while the desired illumination power depends on the sensitivity of the receiver used and reflectivity of the target at the used wavelength. The size of the target area is the remaining variable, and will decide over the viability of this detection method. Radar frequencies may be used for active instruments. For the desired purpose of imaging, Synthetic Aperture Radar (SAR) may be of particular use, while general radar from orbit will not provide applicable results.

4.3 Passive EMR

Viability of passive methods strongly depend on the emissions of the observation targets. Thermal infrared emission is largely dictated by the temperature of the object, though detection also requires contrast to the background, and thus a temperature difference to the surroundings. Information on this was only mentioned for the Nimitz incident where Navy infrared cameras were used. Visual frequencies may be reflected during daytime, or actively emitted during nighttime. The former was the case in most reports, while the later was also observed in some. Radio emission require active emission by the target in question, though have been reported in some instances. These are likely to be of relatively low emission power, resulting in low receivable power at orbital heights. Localization and imaging of such emissions may require a large dish or antenna.

4.4 Other

Other methods, such as ones based on magnetic fields or gravity variations were deemed to be generally non-applicable, as the targets are small and distant. Furthermore, no reports conclusively indicates other properties measurable over long distances.

4.5 General viability of methods

4.5.1 Active visible and infrared

The realistically available power in a package of under 30u is discussed in further detail in section 8.2. However, it lays below 1kW, which, over the distance of 500km results in a significant drop of signal strength. Useful visual or IR illumination would be limited to very small areas, not meeting the desired goal of large coverage. In addition, such illumination is sufficiently available from the sun during daytime. Due to this, these methods are not further investigated.

4.5.2 Synthetic Aperture Radar

The available power will likely also limit the coverage area of a SAR system, though not as significantly. The viability of SAR systems on nano satellite platforms has been demonstrated in multiple missions. This method could however not be further investigated in the scope of this study, due to the high complexity involved and lack of expertise in the field of SAR by our team. Effects of fast movements by the target objects would be unclear, and could not easily be compared against other methods. A further investigation into detection of UAP by SAR may still prove worthwhile.

4.5.3 Passive visible and infrared

For passive methods, the factors important for this study, resolution and coverage area, are dictated by the optics employed. Optics within the available size of the satellite platform can achieve acceptable resolutions and coverage areas, making these methods fit for further investigation in this study.

Observations in the far infrared however are challenging as most common sensors require active cooling, and a comparably large optical system. This, together with the lack of conclusive evidence for the visibility of UAP in the far infrared, leads to an exclusion from further investigation in the extend of this project.

4.5.4 Passive radio-frequency

An antenna or dish of realistic size to be transported within the given satellite size, even for unfolding or otherwise extending variants, would provide very low resolution. A 3 m K-band (10 mm) receiver would reach a ground sampling distance of no less than 2 km. Coupled with the likely low emissions of the targets in question, it is unclear whether this method would be able to reach a useful signal to noise ration, and will thus not be further investigated.

4.5.5 Final decision

Due to the reasons discussed above, visual and near infrared passive observation were chosen as the primary method for this proposal. Active methods would exceed the power budget available, while passive radio-frequencies would require too large antennas. SAR might be usable, though our team has insufficient expertise in the field to reach a judgment on its viability.

5 Challenges of correct detection

An important consideration for instrument selection as well as operation and data processing is the nature of similar, known phenomena that pose the risk of false positive detection. Following, these will be evaluated for both infrared and visual passive observation, the methods chosen for further investigation. Additionally, the variable occurrence of these, depending on type of terrain and time of day in the area, mainly water or land, and day or night, will be considered.

5.1 General challenges

Visual observation during night is limited to artificial lights. These are common on land, and vary strongly in color, brightness and movement. Over water, lights are significantly less frequent and tend to move more predictably. An identification and classification is necessary in addition to mere detection, though will likely prove comparably simple.

Visual observation over land during day presents a wide variety of objects and surroundings, providing a difficult environment for object identification and classification. However, as many other earth observation missions face the same issues, already existing systems may be adapted to address these challenges. Similar conclusions are applicable to maritime daytime observations, though with a more limited scope of possible objects and phenomena to consider.

Infrared emissions are primarily dictated by temperature and emissivity of the subjects. As known structures larger than a few meter rarely differ significantly from the surrounding temperature, the imaging largely captures differences in emissivity, with comparably low contrast. This results in false detection possibility similar to the visual spectrum, to be treated in a similar manner. An object that differs significantly from the surrounding background temperature, and thus delivers high contrast, would however be a strong indication of an actual unknown phenomena.

5.2 UAP-specific considerations

The commonly observed characteristics elaborated in Chapter 3 can be used to further evaluate the confidence of detection with either visual or infrared observation. One set of characteristics are high speed, high acceleration and rapid changes in acceleration. Comparable speeds in excess of half the speed of sound are almost exclusive to aircraft, making such objects distinguishable from all other know terrestrial phenomena. High accelerations in excess of 10g and rapid changes in acceleration are not exhibited by known terrestrial phenomena outside of rare aircraft maneuvers, giving a basis for reliable detection. It is however still important to consider other phenomena, like optical artifacts, such as sun reflections and lens flares, or cosmic phenomena, such as cosmic radiation impacting the instrument or auroras.

Sizes, forms, colors, and other characteristics vary over reports, and are largely not significantly different from known phenomena. While relevant for further classification, these are not reliable enough for primary distinction between known and unknown phenomena.

6 Payload capability requirements

This chapter describes the calculation of the requirements for an optical sensor capable of UAP detection based on the assumptions made in chapter 3 and assesses the proposed instruments according to these requirements.

The satellite speed v_{sat} can be calculated using the gravitational constant G, the mass of the earth M, the radius of the earth r_{earth} and the satellite orbit height h_{sat}:

$$v_{sat} = \sqrt{\frac{GM}{r_{earth} + h_{sat}}} = 7611 \frac{m}{s}$$

The maximum relative speed satellite to UAP along v_{al} and across v_{ac} track can then be calculated using the equatorial rotation speed v_{earth} and the estimated maximal speed of an UAP v_{uap}. For this calculation the inclination is assumed to be 90°, which is not correct for a sun-synchronous orbit, but sufficient for the estimation of the payload capability requirements.

$$v_{al} = v_{sat} + v_{uap} = 27611 \frac{m}{s}$$

$$v_{ac} = v_{earth} + v_{uap} = 20464 \frac{m}{s}$$

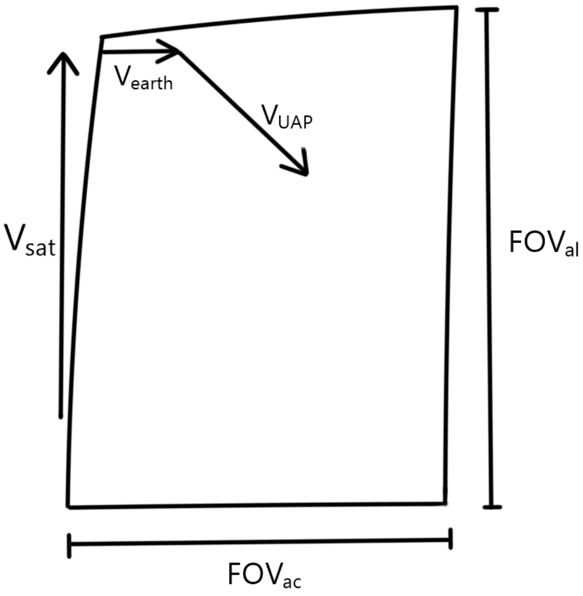


Figure 6.1: Sketch describing the velocity vectors and resulting observation area

Using the targeted frame rate (variable) f and the minimal number of frames required to be able to detect a UAP in these frames f_{min}, these velocities can be converted into the worst case required coverage lengths d_{al} and d_{ac} at the maximal flying height h_{uap}:

$$d_{al} = \frac{f_{min}}{f} v_{al} = \frac{f_{min}}{f} \cdot 27611 \frac{m}{s}$$
$$d_{ac} = \frac{f_{min}}{f} v_{ac} = \frac{f_{min}}{f} \cdot 20464 \frac{m}{s}$$

This can be converted to the according ground level coverage lengths (Field of View) in the case of looking vertically down to the surface:

$$FoV_{al} = \frac{h_{sat} - h_{uap}}{h_{sat}} d_{al} = \frac{f_{min}}{f} \cdot 26230 \frac{m}{s}$$
$$FoV_{ac} = \frac{h_{sat} - h_{uap}}{h_{sat}} d_{ac} = \frac{f_{min}}{f} \cdot 19441 \frac{m}{s}$$

This leads to the following required field of view for each of the proposed sensors (described in section 7.3) for $f_{min} = 3$:

Large Imager

$$FoV_{al} = 5246m \geq 3840m$$
$$FoV_{ac} = 3888m \geq 3072m$$

Medium Imager

$$FoV_{al} = 1311m \leq 7680m$$
$$FoV_{ac} = 972m \leq 7680m$$

Hyperspectral Imager

$$FoV_{al} = 1574m \leq 4608m$$
$$FoV_{ac} = 1166m \leq 2304m$$

Therefore the Medium Imager and Hyperspectral Imager are usable for UAP detection of all speeds, while the Large Imager is only usable for UAP detection with speeds up to 12.6 km/s ($FoV_{al} = 3840m$).

7 Payload draft

Based on the previously specified requirements, the viability of possible payload designs and instruments will be evaluated, and two designs suggested as a starting point for further design and development.

7.1 Existing Instruments

Earth observation is the most common application of nano satellite systems [10]. As such, there exists a large variety of such payloads, particularly operating in the visual spectrum. Commercial operations by companies such as Planet Labs Inc. and Spire Global Inc. have been ongoing since 2013 [10]. These are based on 3U satellite systems, though 1U, 2U, 6U and others have also been successfully operated (see Figure 7.1).

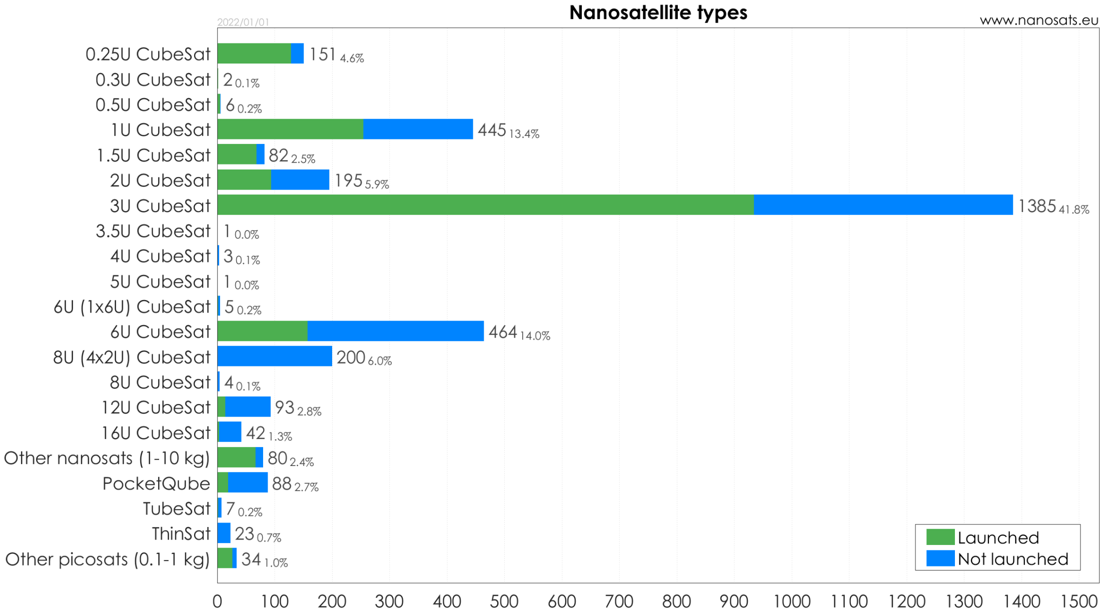


Figure 7.1: Number of launched and planned nano satellites by size [11]

Larger platforms as envisioned for this project are currently still rare, though increasingly common in plans for future missions. Complete instruments will thus likely be of little value to consider as they are designed for smaller systems and not specialized on the mission at hand. In addition, new imaging by a different satellite would likely prove largely redundant in comparison to analyzing existing imagery.

7.2 State of imaging technology

The main focus here is placed on the imaging sensors, as the biggest innovations and improvements for imaging systems are focused on these. The improvements to optical systems will not be covered.

Sensors used in commercial instruments may be of particular interest, as they could be repurposed for a specialized instrument, and have flight heritage. However, the technical details of these are difficult to find, likely due to the private nature, which could also make acquiring difficult.

There are however commercially available sensor systems with flight heritage, such as the ones offered by Teledyne Imaging [12, 13]. As there is a variety of sensors available, the one used still remains variable for the final design. As such, currently available sensors that fulfill the measurement requirements will be picked for the suggested designs as a feasible stand-in.

An additional option is posed by off-the-shelf sensors without or with little flight heritage and satellite-grade validation. These offer higher resolution, readout speeds, and lower prices, but would require dedicated validation and more extensive testing. Regardless of this, the differences to satellite-qualified hardware is not significant enough to affect the feasibility of the system.

7.3 Choice of sensors

Due to the high speed nature of the measurements, high image frequencies and global shutter is required as to not create artifacts. As such TDI (Time Delay Integration) sensors are less viable for high resolution images, favoring regular CCD and CMOS sensors. The two most relevant parameters for further estimation of the optics are the pixel size, and number of pixels. Secondary parameters for evaluation of the measurement performance are the read-out speed, wavelength-dependent sensitivity and power draw.

Depending on whether they are space-rated, price, and size, the pixel size and number varies, though the pixel size generally is between 1 and 10 microns. The number of pixels can be picked from a few hundred, to 4096 or more pixel per side. Representative of that spread, two flight-proven sensors were picked:

Teledyne Imaging Ruby sensor [12]

- Type: CMOS
- Resolution: 1280 x 1024
- Pixel size: 5.3 µm x 5.3 µm
- Sensor area: 6.78 mm x 5.43 mm
- Frame rate: 60 fps at full resolution
- Sensitivity: 200 - 1000 nm

Teledyne Imaging Capella sensor [13]

- Type: CMOS
- Resolution: 2048 x 2048
- Pixel size: 10 µm x 10 µm
- Sensor area: 20.48 mm x 20.48 mm
- Frame rate: 15 fps at 12 bit pixel depth
- Sensitivity: 400 - 1000 nm

To provide hyper-spectral imaging capabilities, the sensor used in the HySI camera of the Chandrayaan-1 mission has been picked as a proven sensor for such objectives. It is to be noted that the sensor was used in a TDI mode, with each of the 512 rows configured for a different spectral band:

CMOS SENSOR C650 sensor [14][15]

- Type: TDI-CCD
- Resolution: 256 x 512
- Pixel size: 50 µm x 50 µm
- Sensor area: 12,8 mm x 25,6 mm
- Frame rate: 50 fps
- Sensitivity: 400 - 950 nm

7.4 Instrument draft

The core part of this draft will be the design of conventional optics to form a visual and near infrared spectrum instrument with the chosen sensors. To reduce size and weight, a mirror optic will be used. A Cassegrain configuration is used, though others may be used and yield comparable sizes.

Two satellite sizes were chosen to present both a smaller, easier achievable version alongside a larger, more capable version. The first is 12U large in a 2x2x3 configuration, while the second is 24U large in a 2x2x6 configuration. This allows for optics with a diameter of close to 20cm. This restraint is picked as optics larger than 20cm are too large to be housed in a satellite smaller than 30u. To provide a capability exceeding common earth observation satellite, an instrument with a diameter over 10cm should be picked. This requires a 2x2 front size satellite, with the length being dictated by the volume chosen.

For the two satellite versions, 3 instruments have been drafted.

	Large Imager	Medium Imager	Hyperspectral
Sensor	Capella	Ruby	C650
Frame rate (Frames/s)	15	60	50
GSD (at 740nm) (m)	3	3.75	9
Angular resolution (arcsec)	1.24	1.55	3.71
Diameter (mm)	150	120	50
Length (mm)	300	290	140
Field of View (km)	3.84 × 3.07	7.68 × 7.68	4.61 × 2.30
Total focal length (mm)	883.3	1335	2777
Primary focal length (mm)	378.75	303	126.25
Secondary focal length (mm)	-450.50	-168.99	-13.32
Secondary diameter (mm)	63	33	3.5

Table 7.1: Properties of the drafted instruments

Instrument 1: Large Imager

This presents the largest instrument for the larger satellite version, providing the highest resolution images out of the three. Due to its size, it can not be used on the smaller satellite, as it would not leave sufficient room for bus components. A sensor with small pixel size was chosen to reduce length of the instrument.

Instrument 2: Medium Imager

For the smaller satellite version, a slightly shorter instrument was drafted, reducing the resolution slightly, though providing a twice as large field of view due to the different choice of sensor.

Instrument 3: Hyperspectral Imager

As the other instruments only allow in spectral differentiation through global masks, it was considered useful to include a hyper-spectral sensor for further data acquisition after initial detection with a different instrument. This sensor has lower spatial resolution and frame rate, which makes it useful as a secondary instrument, rather than for initial detection, since it is small enough to be installed supplementary to a primary instrument on either satellite version.

Instrument 4: High-FoV Side Camera

In addition a fourth instrument may be added to either satellite. To allow for longer duration tracking after initial detection, a smaller, lower resolution camera with lens optics and a high field of view could be included. The optical system of this was not specifically considered, though is deemed non-critical for the feasibility of the system, especially as the inclusion is optional.

Satellite 1

Satellite 2

Figure 7.2: Instrument layout without other satellite components. Satellite 1 is equipped with Instrument 1, 3 and 4, while Satellite 2 carries Instrument 2 and 3.

The arrangement of instruments as well as their relative dimensions are illustrated in Figure 7.2. Their full drafted arrangements can be seen in Figure 8.1 and 8.2.
Instruments 1 and 2 allow for measurements with sufficient precision to detect UAP within the mission requirements and likely offer sufficient data to distinguish them from natural phenomena, dependent on ground data processing. They also enable movement analysis, especially when enhanced with Instrument 4 for long range tracking. Instrument 3 would also provide spectroscopic analysis in either satellite version.
However, likely non of the instruments would be able to resolve details of UAP under a few meter in size. This would require larger instruments and as such a larger satellite outside the mission constraints.
Both drafts provide similar data, with Satellite 1 achieving slightly higher resolution as supposed to Satellite 2's higher frame rate. Due to its smaller size, Satellite 2 would likely be more feasible within the near future.

8 Satellite bus considerations

To get a more complete assessment of the viability of such a mission, the rough bus requirements have been outlined and evaluated through models of the satellite configurations, yielding available bus volume and solar panel area.
A more detailed assessment and draft of bus components was not conducted, as it is not included in the scope of this study, and is only considered with respect to its relevance to the payload design constraints.

8.1 Bus volume

A core constraint applied to the instrument design was the needed remaining volume for bus components. This was set to be around 50% of the satellites volume. While the components contained within are not considered more closely, this was deemed a realistic ratio between payload and bus. The volumes derived from the model are in relation to the indicated sections. More space around the instruments may be used, though provide more demanding constraints on the components placed there. In addition, the outer most areas of the satellite were left empty, to allow space for potential mounting and deployment hardware.

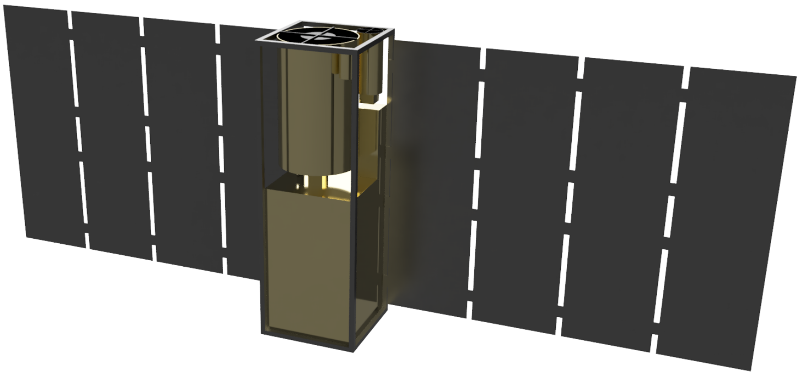


Figure 8.1: Complete configuration of Satellite 1 (2x2x6) with instruments, bus and extended solar panels

In satellite 1, a bus volume of around 10 dm^3 was identified, out of a usable internal volume of 18.8 dm^3, making up 51.7 %.
In satellite 2, this was found to be around 4 dm^3 out of 9.1 dm^3, resulting in 44.9 %.
Both stay close to 50 % of the volume being used for the instrument and bus respectively, making the sizing of bus and instrument plausible.

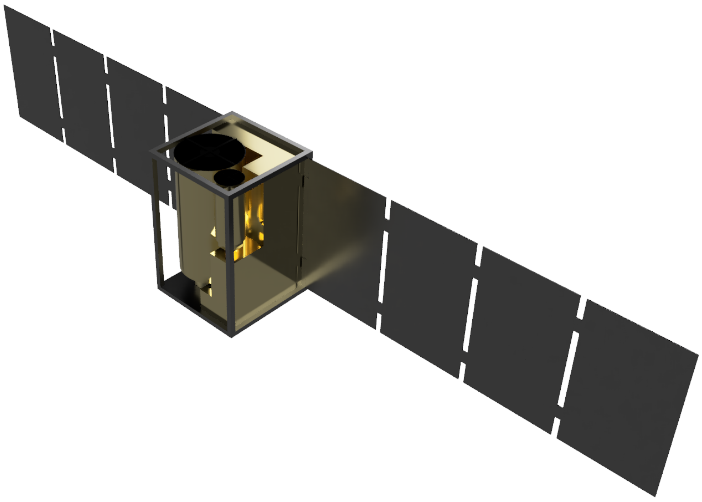


Figure 8.2: Complete configuration of Satellite 2 (2x2x3) with instruments, bus and extended solar panels

8.2 Power supply

The driving factor for many design decisions in the design of a spacecraft is the limited power budget available. For almost all long term missions, the power is provided by solar panels. Continuous power during eclipse is dependent on batteries storing excess power during illumination. The power collection of solar panels depends on their efficiency, area, and illumination angle. Typical efficiencies of space-born panels range from 20 % to 33 % [16], with a solar flux of 1367 W/m^2 around the earth [17]. This would result in a peak power of 275 ∼ 450 W/m^2.

The selected near-polar orbit of 500 km consists of around 59 minutes of illumination and 36 minutes eclipse. As the mission design demands a near constant Nadir orientation for observation, and fixed panels have been selected to reduce complexity and parts, the angle of illumination varies throughout the orbit. This yields an average effective illumination of 70.3 % outside the eclipse. Including the eclipse time, the solar panels would produce about 120 ∼ 200 W/m^2 average power across the orbit.

The design of satellite 1 includes about 0.75 m^2 of solar panels, providing around 100 W of power on average across an entire orbit. Satellite 2 at half the size and solar panel area provides around 50 W of average power.

To provide a reduced power of around 25 W over the 36 minutes of eclipse, the batteries need to store about 15 Wh. Doubling this as extra margin for safety and increased battery lifespan, using LiPo batteries, would require 115 ∼ 300 g or 0.045 to 0.12 dm^3 of batteries. [18] Batteries of such sizes are already in wide spread commercial use in applications such as tablets and drones, or can otherwise be constructed of multiple smaller batteries.

8.3 Power consumption

Comparing the available power to the power needed by the satellite systems will allow a determination of possible operation modes.
The following are rough estimations of expected power, independent of duty cycles, based on other comparable systems [19][20][21].

- Attitude Control: $\sim$ 5 W
- Data Downlink: 5 $\sim$ 60 W
- Communication and Control: $\sim$ 5 W
- Non-instrument computers: $\sim$ 5 W
- Sensor: minimal
- Data handling: $\sim$ 5 W
- Data processing $\sim$ 10 W

A X-Band antenna as a data downlink would require 60 W during operation, though a low duty cycle, depending on the volume of data gathered. The remaining systems have a collective power draw of about 30 W, giving leaving sufficient margin even on the smaller satellite 2. The solar panel area on satellite 1 may be oversized and could be reduced, though may be useful to compensate for degradation over the lifetime of the satellite.

Data processing with machine learning could be achieved by boards such as Nvidia Jetson, as is currently under study in the Sonate 2 mission [22]. This could provide significant on-board processing ability, using 10 to 20 W [23].

9 Data processing concept

Various limitations require a complex data processing concept.

Due to the acquisition nature video data is generated which is by default one of the largest data type possible (71 % of global internet data traffic is estimated to be video data [24]). For use in a scientific context lossless compression is desired, which further enlarges the data amount. Observation time should be maximized due to the rarity of UAP occurrences. Assuming permanent recording the entire data amount isn't feasible to transmit to the ground due to ground station connection limitations and downlink transmission power limitations. Full UAP detection and analysis is not possible on-board due to the limited computation power available.

9.1 Maximum data amount estimation

The sensors produce up to the following amount of uncompressed data (calculated from pixel amount, maximal framerate and bit depth):

- Large Imager: 90 MB/s
- Medium Imager: 75 MB/s
- Hyperspectral Imager: 5 MB/s

Therefore, up to 170 MB/s of uncompressed data are generated. With compression the data amount can be reduced around 66% according to [25], but the real time capabilities of the used compression methods are unknown.

9.2 Architecture

Due to the limited data transmission capabilities and the coverage maximization target data filtering on the satellite is required. Two different on-board filtering architectures can be considered. The first approach, as depicted in Figure 9.1 only stores UAP detections on a trigger by the UAP detection algorithm. An alternative approach would record all available data until the on-board data storage is full and then override data sent to the downlink and data with the lowest UAP detection score. This approach would provide better data for parameter configuration but would lead to higher hardware wear.

In the ground segment processing intensive UAP analysis, permanent storage and manual analysis are possible. Due to the countless possibilities of further analysis the ground segment specification is not done in this work.

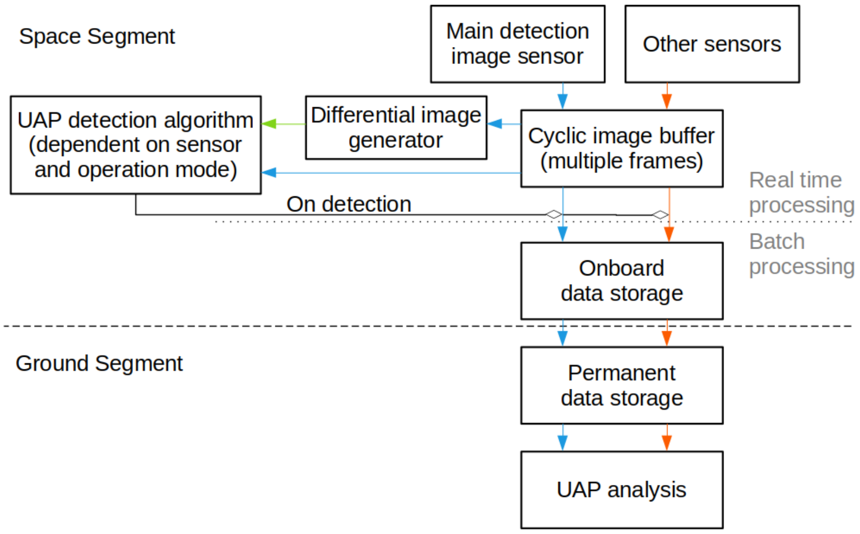


Figure 9.1: Data processing software architecture

9.3 Onboard UAP detection concept

For on-board UAP detection the following pipeline is necessary:

1. Image pre-processing: Pre-processing of the image on a per pixel basis for the object detection. This step may not be necessary in some operation modes and with some detection algorithms. This step may consist of a differential image generator which subtracts the current image from the previous image with consideration of the expected offset due to satellite motion to filter any stationary ground object. If the available computation power does not suffice to run the detection pipeline with full resolution, a downsampler may be used.

2. Object detection: This step should find distinct objects inside the pre-processed image. This step may consist on a light level based segmentation algorithm or a real time capable feature detector.

3. Object description: Transformation of the detected objects into a lower dimensional, rotation independent and possibly scale independent representation. This representation is necessary to be able to associate found objects with objects from previous images.

4. Object analysis: This step should analyze the detected objects in terms of movement and potentially shape to determine a UAP likelihood. Existing object movement analysis algorithms can be used, the UAP likelihood evaluating algorithm has to be developed for the satellite due to the first time application. Some components from existing ground based UAP detection software can potentially be reused.

5. Persist decision: This step should decide based on the UAP likelihood determined in the object analysis if the images around a certain object are worth persisting into permanent storage.

9.4 Configurable software parameters

Cyclic image buffer size: This parameter changes the availability of recent images for storage on UAP detection. This parameter is limited by available volatile memory.

Minimal amount of data points for UAP detection: This parameter changes the minimal required data points of a tracked object to determine UAP classification.

Operation mode velocity and acceleration limits: All UAP detecting operation modes have velocity and acceleration limiting constraints in which known phenomena are expected. The minimization of these constraints is wanted for the ability to detect a large variety of different behaving UAP. Depending on real world performance of the detection algorithms an additional filtering with expected brightness, size and directional changes as parameters might be needed.

10 Operation modes

10.1 Nighttime over sea

A dark background with no or only few light sources contained is expected. Only glowing UAP can be detected at nighttime, therefore the object identification algorithm is only required to find light sources. Light sources moving with no or constant velocity vector (<Mach 1, <0.2 g acceleration) are likely to be known phenomena (airplanes, ships). Flashing stationary lights can be assumed to be thunderbolts. Every other light source is likely to be interesting for further analysis.

10.2 Nighttime over land

This operation mode is comparable to section 10.1 with more and stronger accelerating expected light sources. A dark background with no or stationary and mobile light sources inside is expected. Light sources moving with no or slow velocity vector (<300 km/h, <2 g acceleration) can be assumed to be known land based phenomena (stationary lights, land based vehicles). Light sources with constant velocity vector (<Mach 1, <0.2 g acceleration) are likely known aerial phenomena like airplanes. Every other light source is likely to be interesting for further analysis.

10.3 Daytime over sea

A constant background with only few distinct objects inside is expected. Objects moving with no or constant velocity vector (<Mach 1, <0.2 g acceleration) can be assumed to be known phenomena like ships, airplanes and clouds. Dark objects are likely to be a known phenomenon like (cloud) shadows. Every other object is interesting for further analysis.

10.4 Daytime over land

Many objects are expected inside the observed areas. Objects with no or slow velocity vector (<300 km/h, <0.3 g acceleration) are likly to be land based or natural aerial phenomena like clouds. Dark objects are likely to be shadows of other objects. Point lights can be assumed to be reflections. Small objects moving with slow velocity vector (<300 km/h, <2 g acceleration) are likely to be known phenomena like land based vehicles. Objects with constant velocity vector (<Mach 1, <0.5 g acceleration) can be assumed to be known phenomena like airplanes. Every other object is likely to be interesting for further analysis.

10.5 Focused area

This operation mode is a variation of the previous operation modes with the difference to focus the satellite on a previously selected area instead of swathing over the directly area underneath. This mode should enlarge the observation time of areas with a high number of known UAP appearances.

10.6 Repeat acquisition

The repeat acquisition should record an area for a repeated time after a (confirmed) UAP sighting for better understanding of the circumstances of the UAP sighting. This will lead to a better understanding of local geographical features and other effects possibly producing the observed phenomenon.

11 Summary and Outlook

In total, this evaluation demonstrates that the two proposed satellites, as well as similar designs, are likely capable of full time observation with on-board pre-processing of the data to enable orbital search of UAP.

Visual detection was deemed most achievable, and instruments were drafted for this application. Based on these, two satellite versions with appropriated size bus and solar panels were modeled, and found to fulfill most of the user requirements. A tactic and structure for on-board data processing specialized for UAP detection was presented to reduce the amount of unnecessary data sent to ground.

Such a platform would supply global data on UAP occurrences, forming a basis for more extensive research of this topic. A nano satellite of 12 to 30U could fulfill this role at a significantly lower cost than a larger system. Existing research and expertise in Germany on machine learning in nano satellites [22], and UAP detection [4] [3] may prove advantageous in future projects. However, a more extensive project with appropriate funding would be needed to realize the satellite concept. The concept could also be expanded to a larger satellite, to provide more varied and higher quality measurements, or multiple satellites, allowing more frequent coverage, depending on the available funding.

As emphasized by military and scientific experts, more extensive knowledge of UAP is highly valuable. A mission such as proposed here would avoid many of the limitations of previous observations, such as small tracking range, giving a more complete picture of the behavior exhibited by some UAP. Such data may be sufficient to narrow the possible causes and sources, and as such provide a deeper understanding of these atmospheric events. With high enough reliability, the satellite could also be linked to other systems, either on the ground, or other orbital assets, notifying them of a detection to collect more data when needed.

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