INSPIRESat-1: Introduction and Feasibility Study for a CubeSat Mission for Middle and Upper Atmosphere Wind and Temperature Observations

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Abstract

Spanning from the altitude range from 20 – 1000 km, middle and upper atmosphere is the region that significantly important to understanding the atmosphere as a whole. The winds and temperature in this region have important implications both for the Low Earth Orbit space environment, as well as understanding vertical coupling process. However, existing satellite measurements of this region are limited in terms of their spatial and vertical coverage. Therefore, compact sounding payloads that may be deployed using small satellites satisfying the payload requirements are needed.

As part of International Satellite Program in Research and Education(INSPIRE), we present a report over the feasibility of utilizing a CubeSat mission carrying the Doppler Wind and temperature Sound(DWTS) instrument, which is being co-developed by CU LASP, GATS and Brandywine Photonics. The report highlights on the analysis, preliminary design, and requirements imposed on all the subsystems for the INSPIRESat-1 mission, as determined by NCU students and in collaboration with Taiwan's National Space Organization(NSPO).

INTRODUCTION

International Satellite Program in research and Education(INSPIRE)

INSPIRE is a multinational-cooperate program to develop constellation of small satellites for cutting edge space and earth science research, a supporting global ground station network, as well as research and educational programs covering spacecraft design, space systems engineering, operations, and data analysis.

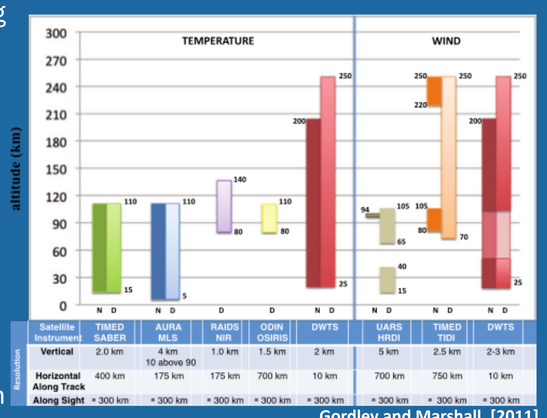
INSPIRESat-1 and Mission:

INSPIRESat-1 is a 6U CubeSat carrying the Doppler Wind and Temperature Sounder (DWTS)

- Mission Goal : Demonstrate DWTS is capable of measuring winds and temperature from 30 – 200 km
- Object of this study : Determine whether such requirements can be met using COTS (Commercial Off The Shelf) components.

Doppler Wind and Temperature Sounder (DWTS)

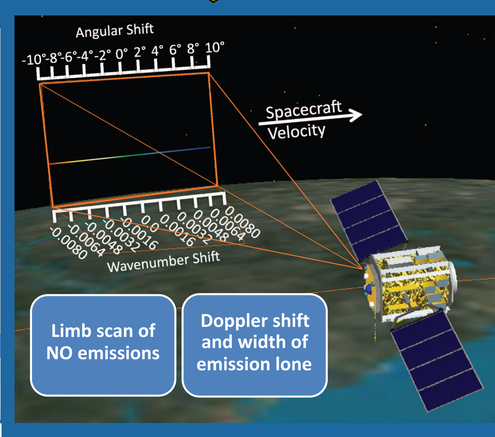
DWTS is a radiometer payload concept developed and patented by the U.S. aerospace firm GATS Inc [Gordley and Marshall, 2011; Gordley et al., 2013]. It is capable of providing continuous daytime and nighttime measurements of winds and temperatures across a vertical range of 25-200km.DWTS utilizes an infrared camera to measure Doppler shifts and widths of NO(5.3μm) and CO2 emission spectra by passing gas cell filter.



Satellite Instrument	TIMED SABER	AURA MLS	RAIDS NIR	ODIN OSIRIS	DWTS	UARS HRDI	TIMED TIDI	DWTS
Vertical	2.0 km	4 km 10 above 90	1.0 km	1.5 km	2 km	5 km	2.5 km	2-3 km
Horizontal Along Track	400 km	175 km	175 km	700 km	10 km	700 km	750 km	10 km
Along Sight	▪ 300 km	▪ 300 km	▪ 300 km	▪ 300 km	▪ 300 km	▪ 300 km	▪ 300 km	▪ 300 km

Resolution

Gordley and Marshall, [2011]



DWTS Requirements and Specification

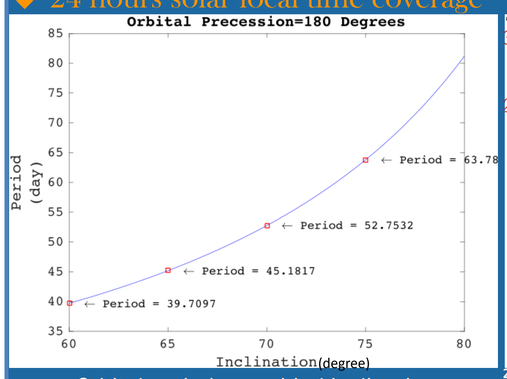
Mass	4 kg
Volume	29 x 10 x 9 cm (3U)
Power	Standby and Operational: 7W Safehold: 1 W ; Off: 0 W
Pointing Knowledge	±0.5 arcmin, all axes
Pointing Stability	< 6 arcsec/sec
Attitude Control	1° all axes
Field of View	Sun must not appear in field of view.
Spacecraft Velocity Knowledge	±1 m/s
Data Rate	Downlink 200 Mega bits/day
Thermal Stability	FPA: ±0.1 K/minute Gas Cell: ±1 K/minute
Thermal Requirement	Anti-Sunward Side: -10 – 0°C
Observed Emission	NO 5.3 μm

Objectives ➡
- Demonstrate that error due to stray light effects can be negligible using optical and digital means.
- Increase TRL from 3 to 9.

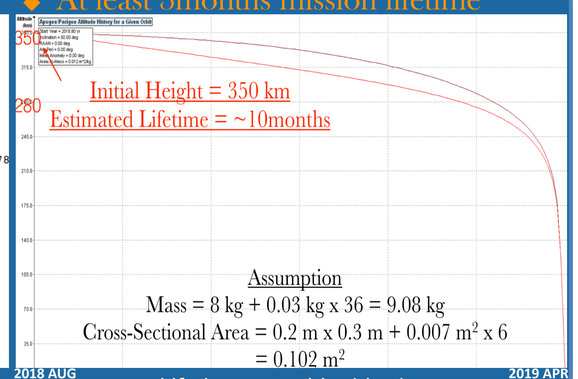
INSPIRE-SAT1 SYSTEM DEFINITION, FEASIBILITY, AND PRELIMINARY DESIGN

Orbit and Navigation (ORB/NAV)

- 24 hours solar local time coverage
- At least 3months mission lifetime



Orbital period v.s. orbital inclination



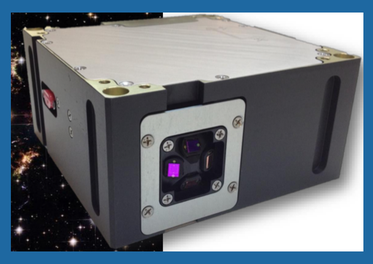
Lifetime v.s. orbit altitude

➡ Orbit: 350km circular , 65° as inclination can survive at least 1 year with solar local time coverage in 45.18days.

Navigation: continuous measurement of spacecraft position and velocity, GPS

Attitude Determination and Control (ADCS)

- Meet the attitude requirement from DWTS



ADCS COTS options and specifications

	XACT Capability, Blue Canyon Technologies
Instruments	1 star tracker, 1 sun-sensor, 1 IMU, 3 reaction wheels, 1 magnetometer and 3 torque rods.
Pointing Accuracy	(1-sigma) for 2 axes (1-sigma) for 3rd axis
Price	USD 139,995.00
Lifetime	3 Years (LEO)
Volume	0.5 U
Electronics Voltage	5 V
Reaction Wheel Voltage	12 V
Data Interface	RS-422

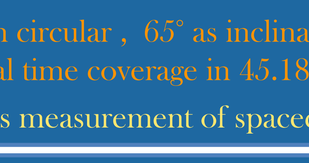
➡ Solve FOV and eclipse problem.

Thermal Control (TCS)

- Ensure all subsystems meet the temperature margin during the mission

- **Orbit 1 : 600 km**
  $T\downarrow MAX = 323.1\ K = 50.1℃$
  $T\downarrow MIN = 203.6\ K = -69.4℃$
- **Orbit 1 : 800 km**
  $T\downarrow MAX = 321.8\ K = 48.8℃$
  $T\downarrow MIN = 200.8\ K = -72.2℃$

Analysis based on radiative equilibrium



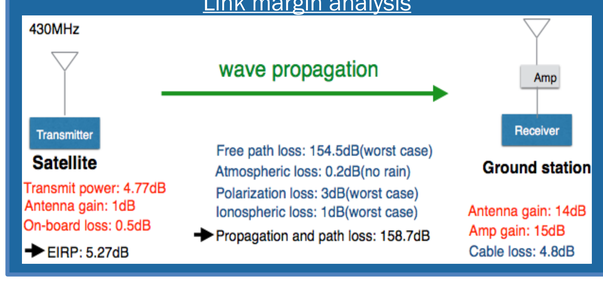
Components	Operational	Survival
EPS	-40 ~ 85 ℃	-50 ~ 90 ℃
Batteries	5 ~ 20 ℃	0 ~ 25 ℃
Solar Panels	-150 ~ 110 ℃	-200 ~ 130 ℃
DWTS Payload	-30 ~ 20 ℃	-25 ~ 25 ℃
GPS	-40 ~ 85 ℃	-55 ~ 95 ℃
Reaction Wheels (ADCS)	-10 ~ 40 ℃	-20 ~ 50 ℃
Motherboard	-40 ~ 85 ℃	-45 ~ 90 ℃
Antennas	-100 ~ 100 ℃	-120 ~ 120 ℃
Radio transceiver	uncertain	-30 ~ 70 ℃

➡ Passive thermal control devices are required for some subsystems.

Communication (COM)

- Link margin of 6 dB
- Downlink data rate 225 megabits/day
- VHF / UHF frequency bands

Link margin analysis



Astrodev Helium 100

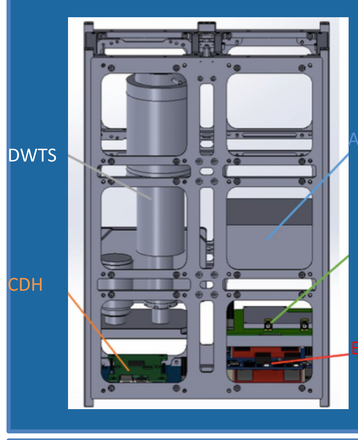
Time access analysis

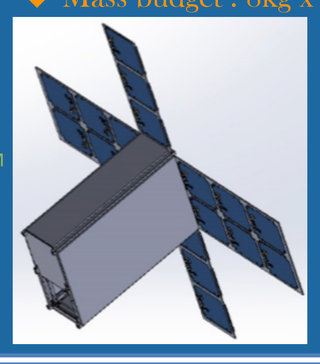
GS	Access time/day
CU	6,250 Seconds
SARC	3,286 Seconds
ISRO	3,444 Seconds
NCU	2,400 Seconds
Total	256mins

Data rate budget≈350 Mbits/day
Link margin=6.16dB

Structure (STR)

- Survive vibration, shock, and space environment
- Mass budget : 8kg x 50% = 4kg





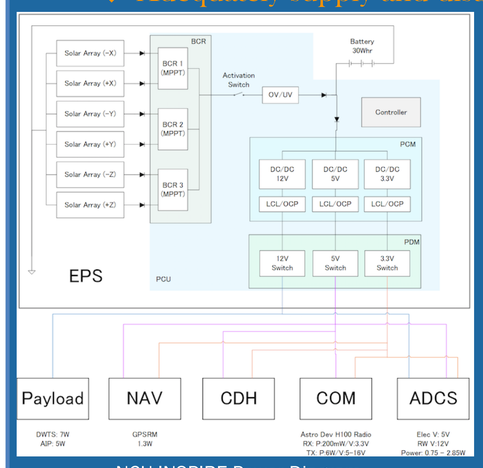
Mass budget analysis

Subsystem	Mass
DWTS	4kg
NAV	0.012kg
EPS	0.2kg/0.6kg
CDH	0.08kg
COM	0.078kg
ADCS	0.85kg
TCS	-
Total Estimate	5.828kg
Margin	2.172kg

Shall consider the thermal control components and antenna.

Electrical Power subsystem (EPS)

- Adequately supply and distribute power to every sub-system in the spacecraft for at least 3 months.



NCU INSPIRE Power Diagram

SUBSYSTEM	COTS OPTION WITH HIGHEST POWER REQUIREMENT
PAYLOAD	7 W (DWTS)
ORB/NAV	1.3 W (GPSRM)
EPS	-
CDH	6 mW
COMM	6 W (Astrodev Helium Radio)
ADCS	2.83 W (XACT)
TOTAL	**17.13 W(maximum)**

Consumption Analysis(Equation [Brown, 2002])

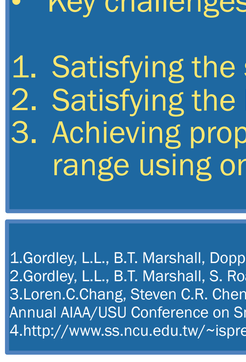
$$P_{sa} = \frac{P_n T_n}{X_{a-b} X_{b-l} T_d} + \frac{P_d}{X_{a-l}}$$

$$E\downarrow req = P\downarrow n\ T\downarrow n / X\downarrow b-l\ DOD$$

Power Require From Solar Panel	
ORBITAL PERIOD	100 minutes
ECLIPSE PERIOD (SPAT Analysis)	1.9758 – 35.0728 minutes
TOTAL POWER CONSUMPTION	17.13 W
REQUIRED SOLAR PANEL POWER (assuming 30% efficiency power loss for all transfers)	25.1709 W to 43.1479 W
REQUIRED BATTERY CAPACITY (assuming 30% efficiency and 80% DOD)	**17.8809 Wh**

➡
1. Solar panel shall provide 44 W of power for the spacecraft.
2. 3.3V, 5V, 12V will be voltage provide to subsystems.
3. The EPS battery shall have a required capacity of at least 20 Wh.

Solar Panel and the Configuration



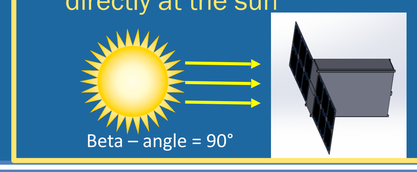
60.36 cm², 3 W at EOL / panel
GOMSpace NanoPower P110

Estimated : 20panels, 1207.2 cm²

Constraint

1. DWTS shall point cross-track
2. DWTS shall avoid pointing directly at the sun

➡ Shall further discuss the solar panel configuration in order to solve the ZERO FLUX problem when beta-angle is 0°



Command and Data Handling (CDH)

Control of all subsystem, primary by interfacing with DWTS

CDH COTS option

- Pumpkin CubeSat Kit
- Past flight heritage.

Operation Mode	Launch	Nominal	Safe	Downlink	Desaturation	Slew

SUMMARY

Our feasibility study shows:
- The subsystem requirements of an 800 km low Earth orbit (LEO) mission can generally be met using COTS CubeSat components, utilized with a 6U CubeSat bus.
- Key challenges identified include

1. Satisfying the spacecraft power requirements.
2. Satisfying the DWTS operational pointing requirements.
3. Achieving proper thermal control to ensure that all components are within their operational temperature range using only passive thermal control mechanisms.

Reference

1.Gordley, L.L., B.T. Marshall, Doppler wind and temperature sounder: new approach using gas filter radiometry, *J. Applied Remote Sensing*, 5, doi: 10.1117/1.3666048, 2011.
2.Gordley, L.L., B.T. Marshall, S. Roark, R. Pierce, A Doppler-modulated gas correlation approach for measuring neutral temperatures and wind in the upper atmosphere, *Proc. SPIE*, doi: 10.1117/12.2022928, 2013
3.Loren.C.Chang, Steven C.R. Chen, Amal. C, Michael. R, Dave. F, Larry. G, John. F, A Preliminary Design for the INSPIRESat-1 Mission and Satellite Bus: Exploring the Middle and Upper Atmosphere with CubeSats, 30th Annual AIAA/USU Conference on Small Satellites.
4.http://www.ss.ncu.edu.tw/~ispre/index.html