The AMSAT CubeSat Simulator: A New Tool for Education & Outreach

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Agenda

- Introduction
- Background
- Demo!
- Spacecraft Block Diagram
- Goals & Requirements
- Proof of Concept Diagram
- Simulator Subsystems
- Ground Station
- Applications
- Future Work / Next Steps
- Acknowledgements

Why a Simulator?

- To demystify and reveal the inner workings of a Satellite
  - That is, "To promote and facilitate the advancement of space technology literacy." - Mark Spencer, WA8SME
- To support educators and provide demonstrations to the public
  - AMSAT's educational mission!
  - Integral part of an education roadmap
- To help CubeSat builders / developers be successful
  - Too many CubeSats are "DOA" upon deployment in LEO
  - A path to success for CubeSat flight missions!

One (Small) Step at a Time

- PROBLEM: Too Many CubeSats "DOA" upon LEO deployment *
- SOLUTION: Build Levels of Competence & Confidence in Satellite Technology

CRAWL	...	Amateur Radio: opportunities & benefits
WALK	...	AMSAT CubeSat Simulator
RUN	...	Engineering Model (EM) or Test Unit (ETU)
FLY	...	Flight Model (FM), Flight Spares & Testing

Original ARRL ETP CubeSat Simulator

Built by Mark Spencer, WA8SME, ARRL Education & Technology Program Coordinator

Transmitted telemetry via CW using TXM-433-LR and RXM-433-LR chips with Excel spreadsheet integration to import and plot voltage, current and other telemetry visually.

Described in The AMSAT Journal September/October 2009 and November/December 2009 issues

http://www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt1-SepOct09.pdf
http://www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt2-NovDec09.pdf

Education with a Satellite Simulator

ETP CubeSat Simulator (Part 1, the technical part)
by Mark Spencer, WA8SME, mspencer@arrl.org
ARRL Education and Technology Program Coordinator

During my interaction with classroom teachers involved in the ARRL's Education and Technology Program (ETP), I encourage the teachers to develop a portfolio of space related activities for use in their classrooms. These activity suggests include, for example, the use of Amateur Radio satellites, NOAA weather satellites, an ARISS contact, Radio JOVE, INSPIRE, and radio astronomy. During the Teachers Institute (http://www.arrl.org/FandES/tbp/ti.html), one afternoon of the 4-day institute is dedicated to bring space into the classroom with hands-on demonstrations of these suggested portfolio activities. Details of many of these activities have been highlighted in *The AMSAT Journal*, *QST* and *CQ VHF* magazines and there have been positive responses to these articles among the non-teacher ham population. This year I had the fortunate opportunity to pilot a Teachers Institute-2 (TI-2) course that focused entirely on using Amateur Radio satellites, particularly satellite telemetry, in the classroom (Figure 2). This initiative proved very successful and it will serve as a model program that is being developed to provide a training course and resources for teachers that are preparing for a scheduled ARISS contact so that the teachers are better prepared to use the ARISS contact, and other space borne resources, in their classrooms long after the ISS has gone LOS.

Figure 1: CubeSat Simulator satellite.

In preparation for the TI-2, I wanted to develop an affordable classroom resource that teachers could add to their portfolio of space related activities to demonstrate satellite fundamentals in a controlled and predictable way so that the more tenuous live on-the-air satellite activity would be more effective as an instructional tool. The result of this effort, the CubeSat Simulator, is described here. This article, part one of the description of the simulator, will focus on the technical side. . In part two of this article, I will list a growing list of possible CubeSat Simulator activities that can be used in the classroom.

This effort really isn't re-inventing the wheel. Professor Bob Bruninga, WB4APR, of the Naval Academy has develop some exceptional hardware for teaching satellite fundamentals, and his work was (and is) inspirational. However, Bob's target audience is the Naval Academy Cadet, a uniquely talented audience. Another readily available satellite simulator resource, EyasSat, is a frequent advertiser in the *Journal*. This simulator is a very comprehensive and capable resource, unfortunately for my program, it has a price tag to match and again the target audience is the university and working professional level.

The target audiences for the ETP are primary, middle, and high school teachers and students. The instructional materials and associated instructional resources for this audience need to be scaled appropriately (appropriate level of rigor, depth, detail, scope, and in today's economic environment, it must be affordable). Also based on my experience with developing other instructional resources, many of the resources developed for schools also have found a place of interest among the general ham population. I anticipate that the CubeSat Simulator will also peak the interest of some readers of the Journal.

The criteria upon which the CubeSat Simulator was developed include:

1. A resource that simulates a satellite operating in orbit as closely as possible in a classroom environment.
2. A resource that can be used to demonstrate the most basic fundamentals of satellite operations.
3. A resource with an open architecture that is easily constructed, modified, adapted, expanded, contracted, explored and used by students and teachers in the typical public school classroom.
4. A resource that is flexible enough to be used at some level by all students.
5. A resource that is rugged and easy to pull off the shelf and get working with minimum preparation time.
6. A resource that will not break the bank.

The CubeSat Simulator is made up of four basic component parts or blocks, each block will be described separately (Figure 3). These component blocks include the CubeSat itself, a 70 cm transceiver used for

Figure 2: TI-2 participants in the antenna farm.

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Top 5 Reasons: Why a Simulator is Better than a Real Satellite

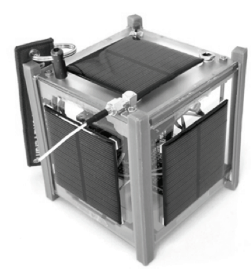
1. Time & Money: A Sim is much more manageable and much cheaper -- you can build your own in far less time and for less than $400!
2. The Wait: You don't have to pay a lot of money and wait years for a launch -- a Sim can be "launched" in any classroom or hamfest on the spot!
3. The satellite Pass schedule: a Sim is available anytime, not just on certain passes at certain times of day
4. Simplicity: You don't need a full ground station to receive telemetry, just a PC with an SDR dongle
5. Engage Others: You can show off a Sim on your desk or shelf as a conversation piece

Who will use a Satellite Simulator?

- Educators in a classroom setting to do exercises that teach aspects of STEM and encourage technical careers
- Those who wish to do public demonstrations so as to, in Mark Spencer's words, "promote a productive, space technology literate citizenry of the United States.
- Teams of explorers who desire an early risk-reducing step in building a CubeSat flight model
- AMSAT and other organizations at public events including Hamvention
- Training & testing tool for satellite developers so that their Ground Station is ready before launch
- Hobbyists who just like to build things and enjoy the Raspberry Pi single board computer and the related simple interfaces

Goals of Producing a New Simulator

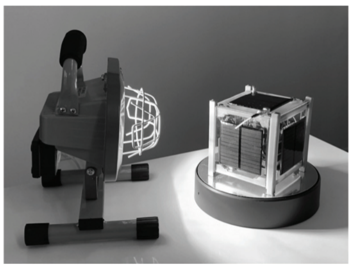
- Replicate many Mark Spencer WA8SME ETP CubeSat Simulator features
- Open source all software and hardware developed
- Have a robust design that makes maintenance simple
- Try to have a look and feel ("Form, Fit & Function") that is as close to a CubeSat flight model as reasonably possible
- Try to have functionality that emulates a CubeSat flying in low earth orbit
- Have a modular design that allows different subsections to be swapped out for alternatives
- Build a community to support and extend the design



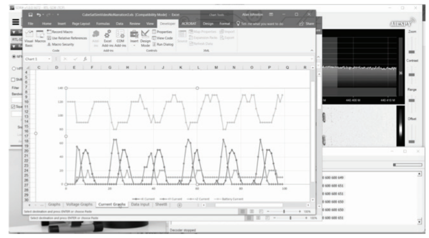
Ready?

Demo Participation

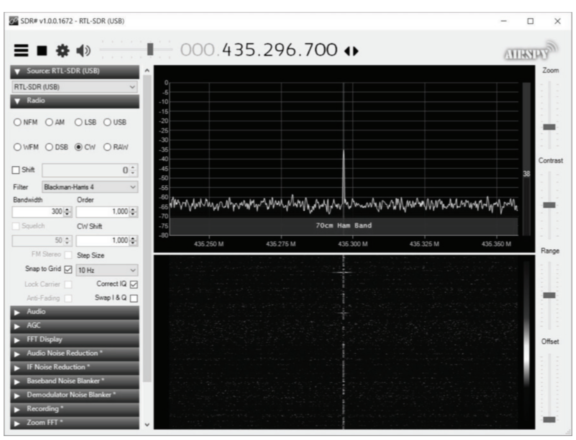
- If you want to participate in today's demo, here are your options:
  - Listen on your radio at
    - 432.297 MHz for CW or
    - 440.389 MHz FM for AFSK 1200 baud AX.25 telemetry
  - Listen on your PC if you have an SDR dongle and antenna

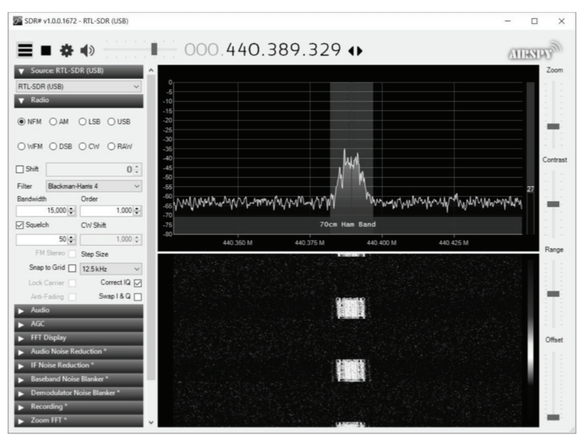


Demo!



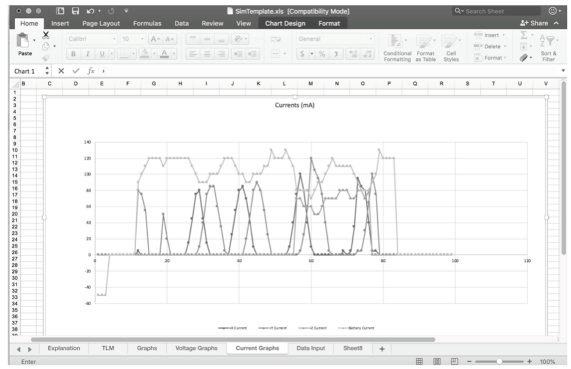
SDR Decoding





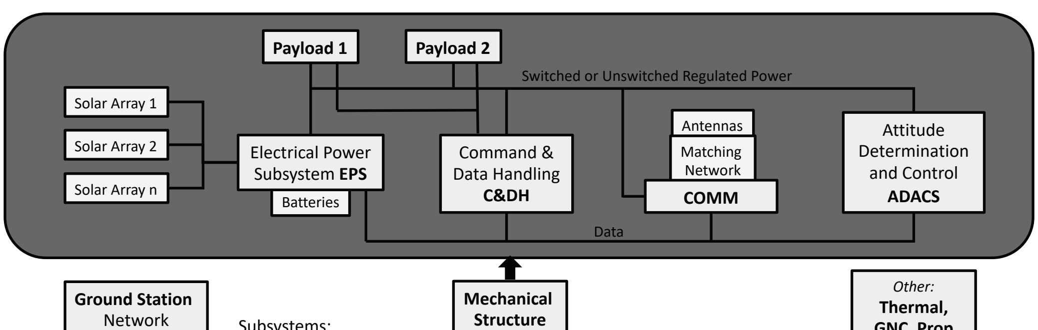
Telemetry Analysis in AO-7 Format

Channel Measured Parameter	Measurement Range	Calibration Equation (Preliminary)
1A Total Solar Array Current	0 to 3000 ma	I = 29.5 N (ma)
1B +X Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
1C -X Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
1D +Y Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
2A -Y Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
2B RF Power Out 70cm/2m	0 to 8 watts	P = 8(1 - 0.01N)^2 (watts)
2C 24 Hour Clock Time	0 to 1440 min.	t = 15.16N (min)
2D Battery Charge/Discharge	-2000 to 2000 ma	I = 40(N - 50) (ma)
3A Battery Voltage	6.4 to 16.4 V	V = 0.1N + 6.4 (volts)
3B Half-Battery Voltage	0 to 10 V	V = 0.10N (volts)
3C Bat. Chg. Reg. #1	0 to 15 V	V = 0.15N (volts)
3D Battery Temperature	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4A Baseplate Temperature	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4B PA Temp. 2m/10m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4C +X Facet Temp.	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4D +Z Facet Temp.	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5A PA Temp. 70cm/2m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5B PA Emit. Current 2m/10m	0 to 1167 ma	I = 11.67N (ma)
5C Module Temp. 70cm/2m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5D Instrument Sw. Regulator Input Current	0 to 93 ma	I = 11 + 0.82N (ma)
6A RF Power Out 2m/10m	0 to 10,000 mw	P = (N^2)/1.56 (mw)
6B RF Power Out 70 cm	0 to 1,000 mw	P = 0.1(N^2) + 35 (mw)
6C RF Power Out 13 cm	0 to 100 mw	P = 0.041(N^2) (mw)
6D Midrange Telemetry Calibration	0.500 V	V = 0.01N(0.50 +/- 0.01) (V)



http://www.om3ktr.sk/druzice/ao7_tlm.html

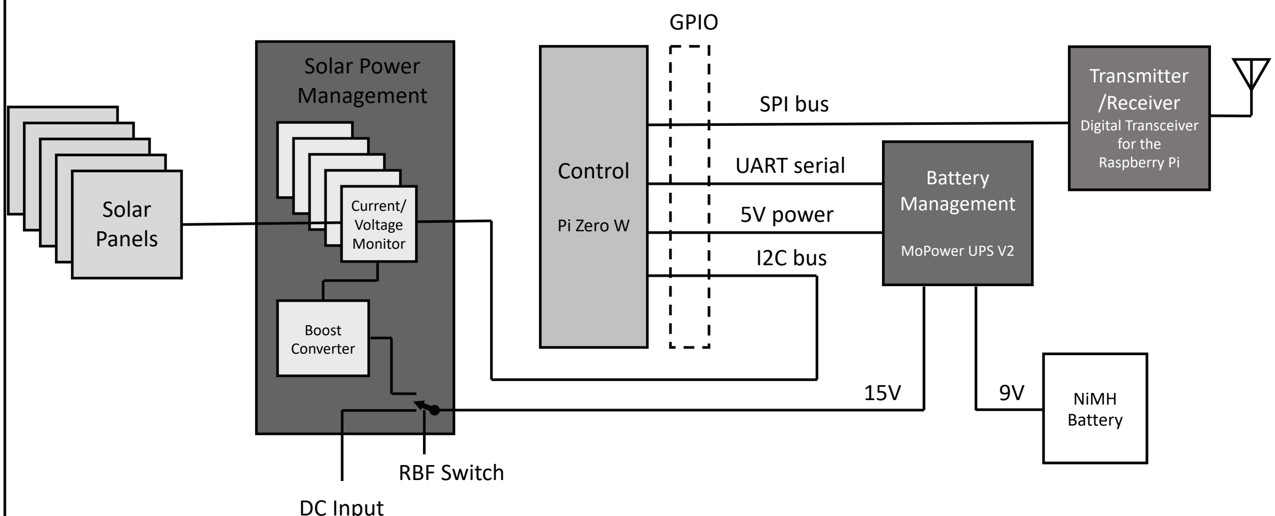
Typical Spacecraft Block Diagram



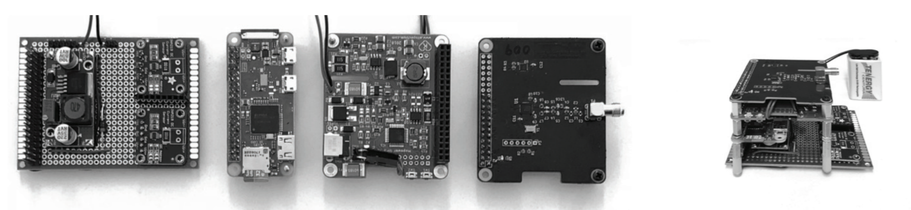
Subsystems:

1. Mechanical Structure: PC/104 standard, PCB stack, interlayer connections, standoffs, fasteners, microswitches, deployables
2. EPS: solar cells, batteries, recharging, power regulating, distribution, grounding, fusing
3. C&DH: On Board Computer (OBC), FSW processing, scheduling, Housekeeping, storage
4. COMM: receivers, transmitters, processor, memory, TT&C, beacons
5. ADAC: multiple sensors, memory, computation
6. Thermal: Temp sensing, heat transfer, computation, control
7. GNC: GPS, RTC, time-stamping data, timing/1 PPS, computation
8. Prop: Propulsion, if we are so lucky, for translation, possibly attitude rotation
9. Payloads: The reason for the mission: Cannot fly without these VIPs!
10. Ground Station: Some seemed as an afterthought. Don't ever let it happen to you!

AMSAT CubeSat Simulator Block Diagram

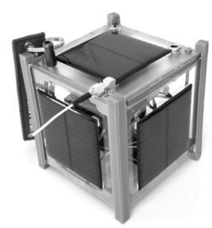


Boards in the Proof of Concept Prototype



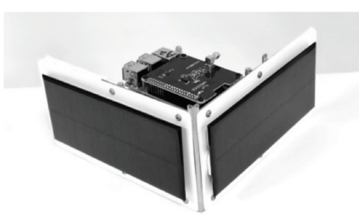
Solar Power Management	Control	Battery Management	Transmitter
Custom Circuit Board	Raspberry Pi Zero W	MoPower UPS V2	Brandenburg Tech Digital Transceiver for the Raspberry Pi
Monitors solar panel current and voltages for telemetry. Boosts voltage to 15 V to charge batteries. Switches between DC input power and solar power.	Runs software to control simulator. Controls and communicates with other boards using the GPIO connector.	Manages charging of 9 V NiMH battery. Provides power on/reboot/shutdown button and automatically shuts down Pi if battery voltage is too low.	Transmits telemetry signal on 70 cm band using different modulation schemes.

1U CubeSat Spaceframe



3D Printer mechanical structures are the way to go if and when a design is shown to be sufficiently robust.

”Winged Frame”



Early in our development we used the steel metal platform and sides left over from the original ETP CubeSat Simulator enclosures by Kurt Spencer, N6SMD, who designed them through Edge Technology, Inc. Unfortunately, only a few remain; they are no longer available from this source.

For a 1U form factor, with a desire to recharge batteries in a more timely or “realistic” fashion, a pair of extended solar panel “wings” were developed for one demonstration model to employ much larger solar cells. Note: Leaving off two sides of the Simulator allow observers to marvel at the working electronics in each layer of the PC/104 standard Printed Circuit Board (PCB) stack.

Some Ideas to Explore

- Team up with a teacher so that he or she can write Lesson Plans more productively for their class or their after school activity
- Explore the Maker movement and show them the excitement and benefits of Amateur Radio and satellite technology
- Write a Fox emulation mode so that the Sim generates DUV telemetry that can be decoded by FoxTelem
- Write a GOLF emulation mode so that we can test out new telemetry before launch -- and to build interest and excitement!

Future Work/Next Steps

- ❑ Give us YOUR feedback on what we have done so far
- ❑ Suggest more IDEAS on how to improve
- ❑ Help finalize prototype design (especially mechanical structure)
- ❑ Contribute pieces of documentation on either the hardware or software to facilitate others in replicating and using the Simulator
- ❑ We will build prototypes and ship them to Beta testers for feedback
- ❑ Our Challenge: to build Sim Prototype units in time for Hamvention 2019

What YOU Can Do

- Think about how you could use a CubeSat Sim at your next meeting, hamfest, or education or outreach activity, and let us know how well this current model works for you
- Write up an activity using the Sim and send it to us
- Volunteer to be a Beta Builder/Tester
  - Build one yourself and let us know how it goes!
  - Receive one of our test units in the mail and use it in an activity
- Volunteer to be on the new AMSAT Education Committee
  - We will discuss future plans for the Sim and other outreach activities
- Spread the word on social media
  - Hashtag **#CubeSatSim** anyone?

Acknowledgements

The Authors would like to thank Jonathan Brandenburg, KF5IDY for his help and assistance. His timely technical support on the Brandenburg Tech Digital Transceiver for the Raspberry Pi Board has been invaluable. Thanks to Mark Spencer for his aforementioned trailblazing work, to NASA summer intern student Nico Lagendyk at UMd-College Park, and to USNA's Bob Bruninga for ideas and inspiration from his undergrad "LabSat" developments.

We would also like to acknowledge all the open source hardware and software that is a part of the AMSAT CubeSat Simulator.

Finally, we would like to acknowledge the support of the AMSAT Board of Directors and AMSAT President Joe Spier for their support and encouragement of this project.

Questions? Comments?

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We are here until Sunday afternoon, so feel free to talk to us anytime!

Backup Slides

Cost of Parts of a Particular Prototype

This is provided to give an idea of the relative cost of parts and components. The actual cost of an AMSAT CubeSat Simulator will vary based on design and choices, which can be modular.

Part	Qty	Cost	Total
Digital Transceiver for the Raspberry Pi board	1	$60.00	$60.00
MoPower V2 UPS board for Pi	1	$60.00	$60.00
Adafruit INA219 DC current/voltage sensor board	5	$10.00	$50.00
Solar Cells, 5.5 V,110 mA 65 mm x 65 mm	5	$5.00	$25.00
Raspberry Pi Zero W CPU	1	$20.00	$20.00
RTL-SDR USB dongle for PC	1	$20.00	$20.00
16 GB SD Card with Raspbian Stretch	1	$18.00	$18.00
AC/DC power adapter 15 V	1	$13.00	$13.00
Clear acrylic sheet 8 x 10	2	$5.00	$10.00
SMA M-M Cable	1	$7.00	$7.00
SMA Cable M-F	1	$6.00	$6.00
2x40 pin stackable header	2	$2.75	$5.50
SMA Antenna 433 MHz	1	$5.00	$5.00
9 V NiMH battery	1	$5.00	$5.00
Various hardware	1	$5.00	$5.00
TRRS plug and jack for RBF switch	1	$5.00	$5.00
SMA 90 degree M-F	1	$3.00	$3.00
1N5817 Schottky diode	5	$0.45	$2.25
DC-DC Boost Converter Module XL6009	1	$2.00	$2.00
Momentary pushbutton switch	1	$1.50	$1.50
Barrel Jack for AC/DC charger	1	$0.75	$0.75
TOTAL			**$324.00**

Educational Roadmap

- Education Requirements
  - Show how solar panels generate power and interact with satellite rotation
  - Show how satellite data (voltage, current, temperature) can be sensed and stored in digital form
  - Show how Ham radio can be used to encode and send telemetry using CW and digital modes over V, U and other bands.
  - Give the experience of copying telemetry as CW or digital with noise and Doppler shift
  - Give visualization of spectrum, modulation, noise, and frequency shifting via SDR reception and FFT and waterfall
  - Allow the experience of analyzing and graphing CubeSat data in spreadsheets
  - Generate export of data and hard copy printout that students can take home with signals and telemetry information
- Practical Requirements
  - Rugged, easy to setup and ship
  - Easy to replace components that wear out and degrade, such as batteries
  - Software configurable radio transmitters so different modes and modulations can be implemented easily in future
  - Work with simple SDR receivers such as RTL-SDR

*References

On LEO CubeSat Failure Rates

- https://www.nasa.gov/sites/default/files/atoms/files/improving_mission_success_of_cubesats_-_tor-2017-01689.pdf
- https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3397&context=smallsat
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- http://web.csulb.edu/~hill/ee400d/Project%20Folder/CubeSat/The%20First%20One%20Hundred%20Cubesats.pdf