CUBESAT CAMERA SPACE RUGGEDIZATION

By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Optical Sciences and Engineering

THE UNIVERSITY OF ARIZONA

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Approved by:

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Dr. Gary Redford
Department of Engineering

Abstract

Professor Vishnu Reddy, from the Lunar and Planetary Laboratory, sponsored a University of Arizona senior design team to “space-qualify” (design, build, and test) a camera system to be integrated into a miniature satellite (CubeSat). This NASA-funded CubeSat mission, named CatSat, will be used as a technology demonstration for a high bandwidth deep space communication system which will be able to achieve HD video transmission from Low-Earth Orbit (LEO) through a novel inflatable antenna.
The camera system, named CatCam, images the deployment of the inflatable antenna and captures video of Earth. The data that CatCam captures streams through the inflatable antenna as the demonstration of HD video transmission. We considered system architecture, camera controls, and integration with the entire CubeSat, and were successfully able to provide our sponsor with a working prototype.

Group Project Responsibilities

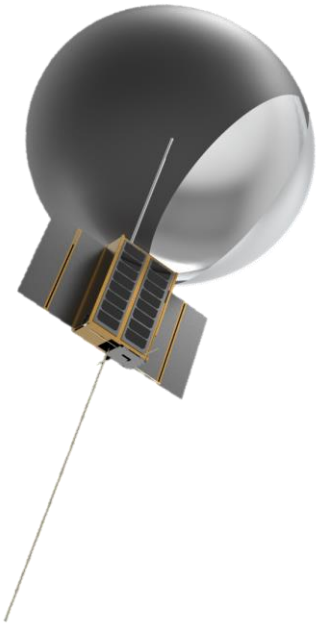
Optical Engineer: Adriana Mitchell
My responsibilities on this project went beyond what is normally expected for an optical engineer on a senior design project. In addition to performing the optical design of the project, I completed the software design, execution and testing for instrument control and data processing required by this project. As an optical engineer I have obtained rudimentary skills in software engineering, using the easily accessible MATLAB provided by the university. This project required me to learn C++ and use it with the skill of a software engineer to design software for a NASA small satellite mission. I was also required to learn how to use the proprietary software development kit provided by the company we purchased the cameras from, in conjunction with C++ on a Linux platform to meet our requirements for the project. After obtaining the knowledge and skills to successfully complete the software engineering, I then went on to thoroughly test the software and hardware to ensure its performance met the specified requirements. I successfully completed the portion of the project that went above and beyond my knowledge and skills as an optical engineer.

Mechanical Engineers: Rishikesh Mallela, Lorenzo Dova
The mechanical engineers performed the testing of the camera casings and helped with the structural design as well as purchasing orders.

Aerospace Engineers: Joe Padish, Sam McCoy
Joe Padish was the team lead. The aerospace engineers designed the camera casings and helped with the testing of the camera casings.

Systems Engineer: Casey Croaker
The systems engineer defined requirements and set testing procedures to ensure our product met NASA standards.

FINAL REPORT
CATSAT CAMERA SYSTEM (CATCAM)



Team 18032

Joe Padish
Sam McCoy
Casey Croaker
Lorenzo Dova
Adriana Mitchell
Rishikesh Mallela

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1.0 Scope

Professor Vishnu Reddy, from the Lunar and Planetary Laboratory, is sponsoring a University of Arizona senior design team to "space-qualify" (design, build, and test) a camera system to be integrated into a miniature satellite (CubeSat). This NASA CubeSat mission, named CatSat, will be used as a technology demonstration for a high bandwidth deep space communication system which will be able to achieve HD video transmission from Low-Earth Orbit (LEO) through a novel inflatable antenna.

The camera system, named CatCam, needs to image the deployment of the inflatable antenna and capture video of Earth. The data that CatCam captures will stream through the inflatable antenna as the demonstration of HD video transmission. We were asked to consider system architecture, camera controls, and integration with the entire CubeSat.

2.0 System Block Diagram

The CatCam system captures and compresses images and video of both Earth's surface and the inflatable antenna of the CatSat CubeSat and then sends the data to the CatSat's main computer to be sent to the ground station. The system design utilizes two identical ruggedized cameras and lenses to capture Earth and the inflatable antenna, while custom camera control software provides functionality to control each camera to compress and output image/video data to the CatSat main computer. In addition to the functionality described above, the CatCam system is designed to be space qualified through the use of space-qualified and/or ruggedized components and testing to ensure the design meets the environmental requirements.

Each camera subsystem consists of a camera sensor housing, camera CCA (camera circuit-card assembly) housing, camera hardware, and dampening materials to mitigate vibration/shock experienced by the system. The camera housing assemblies mount directly to the CatSat frame (see mechanical interfaces in system block diagram, Fig 2-1), and a Pixelink Flex Wire connector connects the camera sensor to the camera CCA. The camera subsystems interface with the camera control software via a USB 3.0 connection to the CatSat main computer, which provides both data and power interfaces for the camera subsystems (see power and data interfaces in system block diagram, Fig 2-1).

The control software runs on the CatSat main computer. The software independently commands both camera subsystems to capture images and video, and compresses the captured data before passing it out to the CatSat main computer.

Figure 2-1 depicts the CatCam system block diagram. It is important to note that the CatSat frame and CatSat main computer exist on the boundary of our system, but are not directly controlled by our team. They exist on the system boundary to show that the camera subsystems (Earth-facing and "Selfie" cameras) mechanically interface to the CatSat frame, and both camera

subsystems interface directly to the CatSat main computer via USB 3.0 for both power and data interfaces.

The “User Input” block shows inputs received by the camera control software from a ground station. These commands will still be passed through the CatSat main computer, however it is shown as a direct connection to the control software to represent only the camera commands passed to the CatSat main computer.

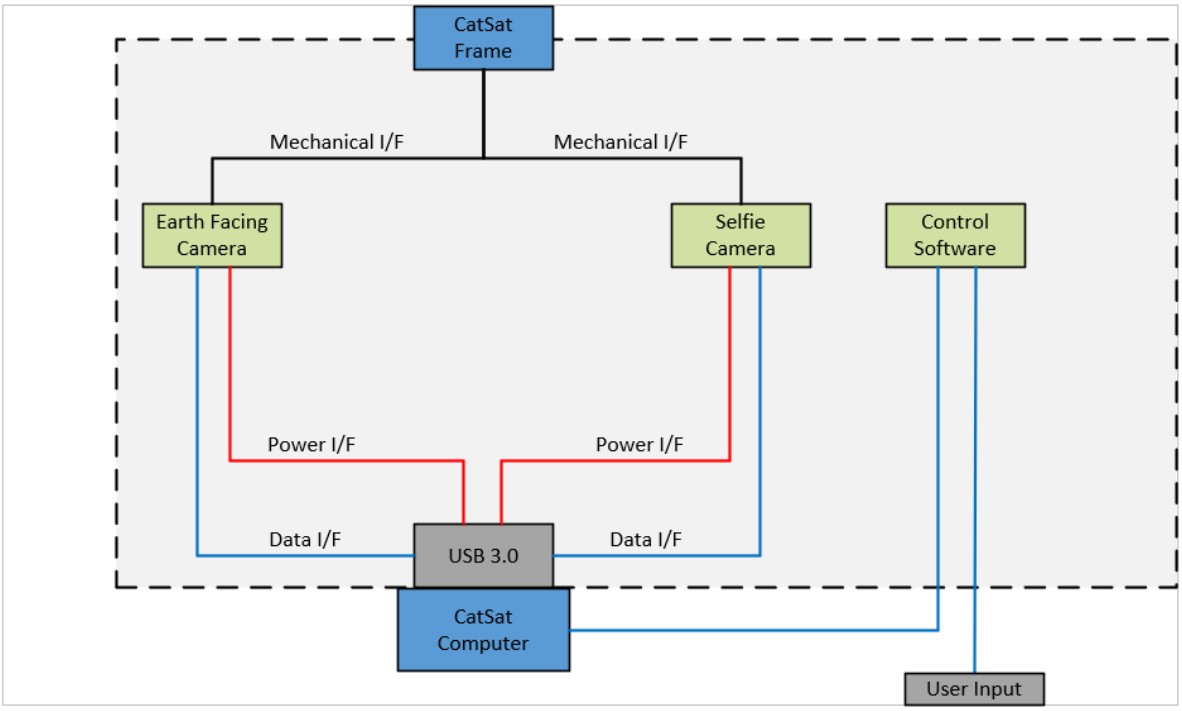


Figure 2-1: System Block

3.0 Technical Data Package

The ATP, SDD, and SRD in their entirety can be found in appendices A, B, and D respectively. Additionally, Appendix C contains all TDP drawings and their .pdf files have been included with this report.

3.1 System Requirements Document

The SRD specifies the requirements given to us by the customer, and requirements that were derived to comply with customer requirements and NASA standards. The requirements have been split into several categories: interface requirements, environmental requirements, customer constraints, software requirements, and performance requirements. A system that fulfills these requirements will be a fully space-qualified camera system that uses commercial off-the-shelf (COTS) camera components.

3.2 Software Design Document Summary

The Computer Software Configuration Items (CSCI) will control both cameras in the CatCam system, acquire images from the cameras, compress the images so that they can be downlinked through the CatSat communication system and then decompress the images to create a continuous full-image video. The CSCI will be able to receive a vector of camera parameters and make the changes to the camera parameters.

4.0 Acceptance Test Procedure

The Acceptance Test Procedure and results can be found in full at the end of this report in Appendix A. The following subsections are high-level summaries of the testing methods used during the CatCam testing phase. The order of testing categories were:

1. Software (continuous)
2. Vibroacoustic
3. Thermal Vacuum
4. System Level

4.1 Thermal Vacuum Acceptance Tests

The CatCam team was able to secure time on the thermal-vacuum chamber in Dr. Walter Harris' (sounding rocket project) laboratory. The purpose of these tests were to verify that the cameras can still function after exposure to the extreme temperatures and pressures expected during the mission, and to measure the amount of outgassing that the CatCam system outputs when exposed to these environments. The thermal-vacuum chamber did not provide any means to connect external devices to the cameras while they were pressurized, so functionality had to be verified before and after the test occurred.

This procedure is quickly summarized by verifying initial image capture, recording initial weight measurement, baking and pressurizing the camera for at least 24 hours, recording final weight and verifying final image capture. The total mass loss (TML, amount of outgassing) is calculated using the initial and final weights, and the image captures verify system functionality. Both camera assemblies were tested simultaneously.

4.2 Vibroacoustic Acceptance Tests

The CatCam team took the camera assemblies to a local engineering firm (Hofstadter Analytical Services) for vibration and shock tests. The purpose of these tests were to verify that the camera assemblies can survive and operate after exposure to random vibrations and shock profiles that are expected during initial launch and subsequent orbit. During this process the CatCam team was able to get hands-on time with the test equipment and assist the staff in running our tests. While the NASA standards give us a 20-2,000 Hz frequency range for random vibrations during vibe testing, there is no standard maximum expected flight environment (MEFE) when testing for shock. There is currently no information available on the CatSat's launch vehicle, and

consequently no MEFE - thus, the shock acceptance test has been marked as a “No Test”. Once more information regarding the launch vehicle is obtained, a shock acceptance test may be conducted.

For the vibration test procedure, each camera assembly was subjected to a random vibration profile between 20-2,000 Hz and at least 6G. Camera assemblies were tested one orthogonal axis at a time, for no less than two minutes on each axis. While at the testing facility, the CatCam team had to quickly design and machine a small bracket with mounting holes for both camera assemblies such that our cameras could be mounted to Hofstadter's vibration table.

4.3 Software Acceptance Tests

We took pictures and video using the camera control software before and after both the vibration and thermo-vac tests to ensure the cameras and camera control software performed optimally, unaffected by the tests. There was no change in the before and after images, so we concluded that the environmental tests did not affect either the cameras or the camera control software.

Because we used a Raspberry Pi to simulate the CatSat computer, we were unable to verify communication with the actual CatSat computer and we were unable to verify turning on the cameras with a command from the CatSat computer, because the cameras automatically turn on when connected to the Raspberry Pi. However, all the other requirements we were able to meet regarding the software through software acceptance tests.

Both cameras were able to independently power on and capture both images and video within a reasonable timeframe from the command being sent. The images captured by both cameras were 1920 x 1200 pixels. The frame rate of the captured video was verified to be 30 fps, as required. The ratio of the input to output files used for video compression was verified to be 32:1. The compression time needs to be improved, as it is not ‘real time.’ i.e. the software first records the video, and then compresses it second. For the software to be properly recording and compressing in real time, the software will need to switch between recording and compressing faster to ensure ‘real time’ capture and compression. Accordingly, the software was unable to meet the ‘real time’ requirement of 40Mb/s.

4.4 System Acceptance Tests

CatCam system-level acceptance tests consisted of two tests that verify that each camera is able to capture images that cover each assembly’s respective image field (Earth’s surface for Earth Camera, inflatable antenna for Selfie Camera). For these tests, a 1:1 scale model representative of the CatSat was 3D printed, with window cut outs to accommodate each camera. The cameras were mounted in the model, images captured to verify the field of view, and compared against the CatSat Field of View model (for the Selfie Camera).

5.0 Models and Analyses

5.1 Sounding Rocket

The CatCam team was given an opportunity to raise our Technology Readiness Level (TRL) on Professor Walt Harris' sounding rocket project. We were given a space in which to test our camera capturing setup to verify that our setup can survive the launch environment. In order for the camera to be onboard the sounding rocket, a case that houses the camera system as well as a Raspberry Pi was designed. There were not strict restrictions on size as long as the entire case fit in a specific area onboard the payload section of the rocket. The case was designed in such a way that the camera mounted to a bracket for easy access, the CCA board mounted to the case away from the camera, and a mounting location was made for the Raspberry Pi, which served as the onboard computer. The CCA board was mounted away from the camera in order to reduce the large amount of heat transfer that was experienced at close locations to the back of the camera. The case has a cutout so that the camera lens can protrude slightly outside of the walls while not having to reduce the wall height and thus the structural integrity. The case was also designed so that it can be bolted to the plate inside the payload section of the sounding rocket.

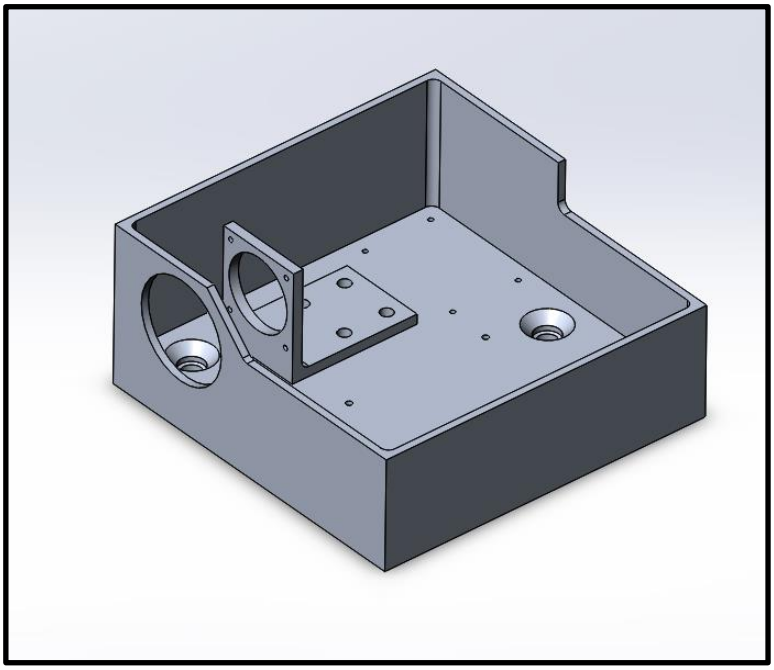


Figure 5.1: Sounding Rocket Case

5.2 Orbital Visualizations

A model of the orbital parameters and physical orbit of CatSat around a model Earth has been created in MATLAB. When the model CatSat's ground track is above 15 viewing degrees of Tucson, the camera plugged into the model is turned on and begins taking and showing video in real time. This model demonstrates that the camera can be triggered to take images in real time. In Figure 5.2 below, the red line represents the satellites actual location in space, whereas the green line represents the satellites ground track on Earth. Based on the satellites orbit and a

requirement of downlinking within the range of 15 viewing degrees from the local horizon, the simulation determines the range of Latitudes and Longitudes outside of Tucson that determine when the satellite is in range for downlinking. The MATLAB code then calls the camera software to turn on the camera and shoot live video while inside the range for downlinking. Upon the satellites decent out of this range, the camera then turns off.

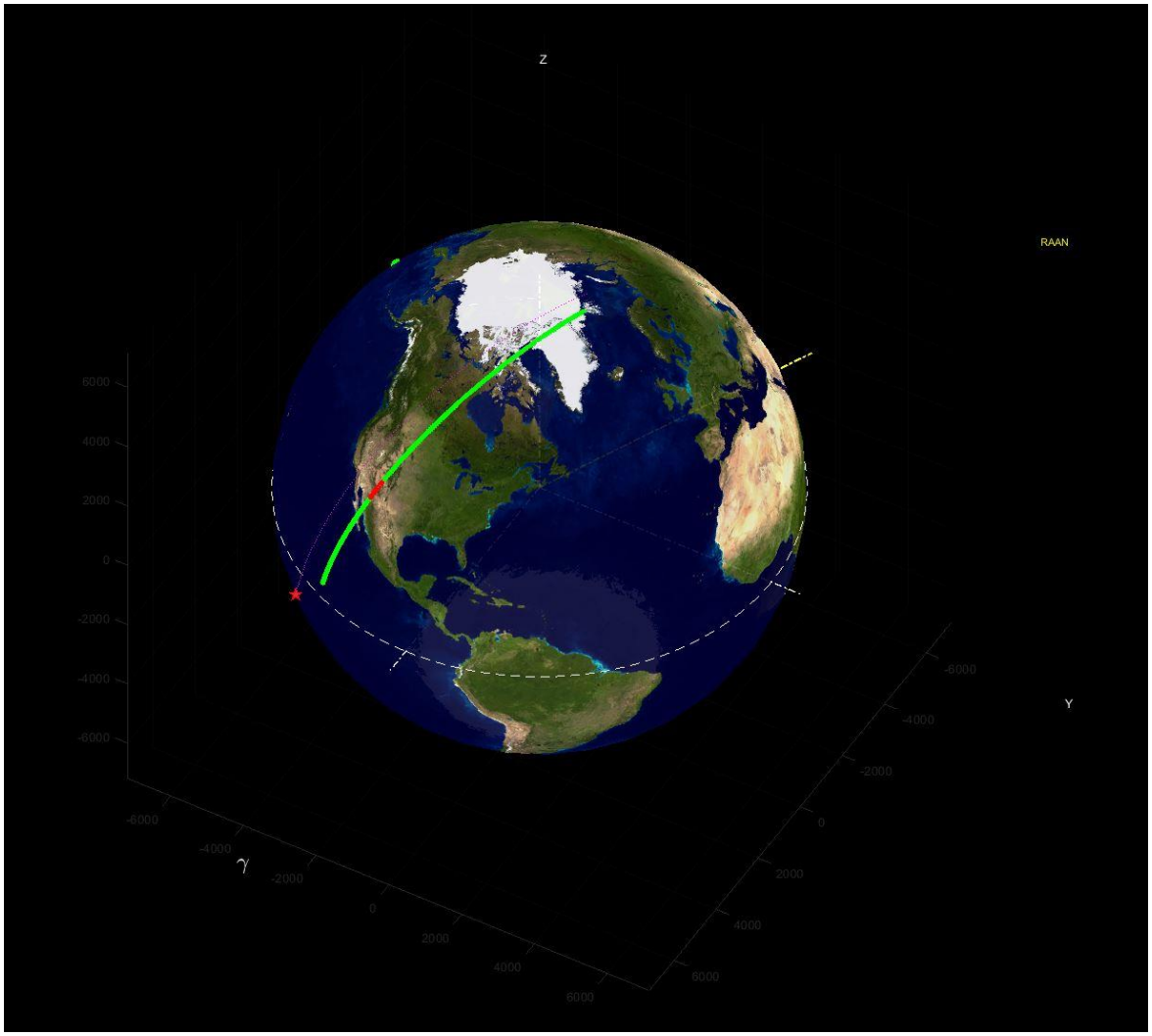


Figure 5.2: CatSat Orbit Simulation

5.3 Models

The Earth Observing Camera serves the purpose of streaming live HD video of Earth from the satellite, whereas the Selfie Camera will be a way of verifying deployment of the large 1 meter diameter antenna. Both camera cases and all camera components were built such that they do not exceed 1U in volume and weigh less than 1kg per the sponsors request. In order for the camera systems to be launched as a NASA payload, they must abide their requirements for vibrations, thermals, and outgassing. During the process of designing the camera structures, analysis was performed in order to determine each of the cases modes of natural frequency. This information was helpful since the camera systems natural frequency must lie outside a specified range of frequencies in order to reduce the chances of resonance with any other structures onboard the

rocket. This range is from 20 Hz to 2000 Hz. Once given the opportunity to take part in the sounding rocket project, it effectively changed the current designs. For the TRL to translate from the sounding rocket project to the CatSat, the way at which the cameras mount must be the same. This is what led to the final camera case designs seen in Figures 5.3-5.4 below. A key feature of the camera cases are that the cameras mount onto a bracket like mount, which is the same as the sounding rocket case. Each of the cases have locations for the CCA board to mount. During initial testing, it was found that the CCA board experienced a large amount of heat transfer from the back of the camera. In order to reduce the likelihood of damage and mitigate the thermals, the CCA board was again mounted in a place away from the back of the camera. For the Earth observing camera (Figure 5.3) this location is below the lens and for the Selfie Camera (Figure 5.4) the CCA board mounts on top of the case. Another key feature of the camera cases is a cutout designed for cable routing. These cutouts allowed the cases to be smaller as clearance between the case walls and the cable did not have to be made.

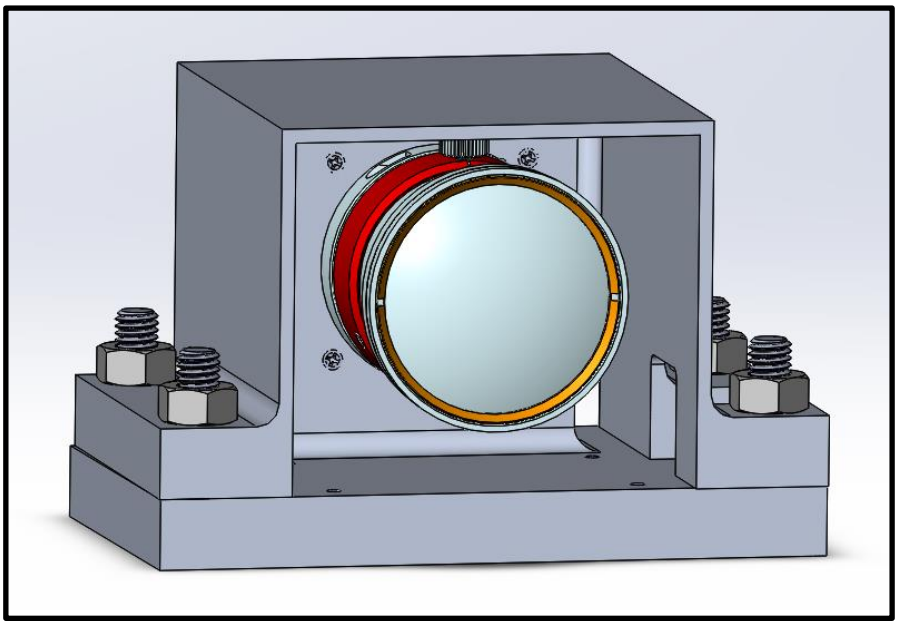


Figure 5.3: Earth Observing Camera Case

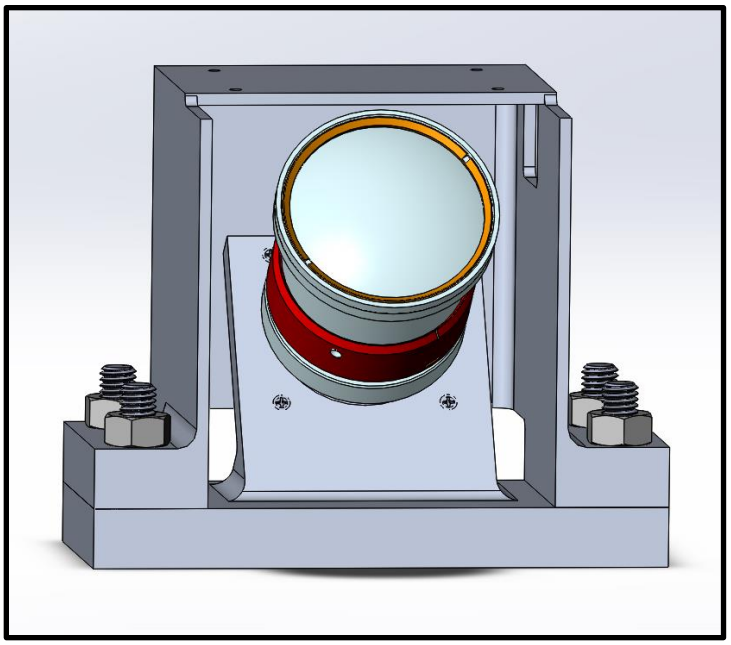


Figure 5.4: Selfie Camera Case

In order for the Selfie Camera to verify the deployment of the antenna system it must be at a angle for the lens field of view to capture the antenna. This angle was determined by designing a to scale CAD model of the satellite with both the antenna and camera systems (see Figure 5.5). The Selfie Camera lens field of view was then added to see which angle is necessary for the camera to view the most surface area of the antenna.

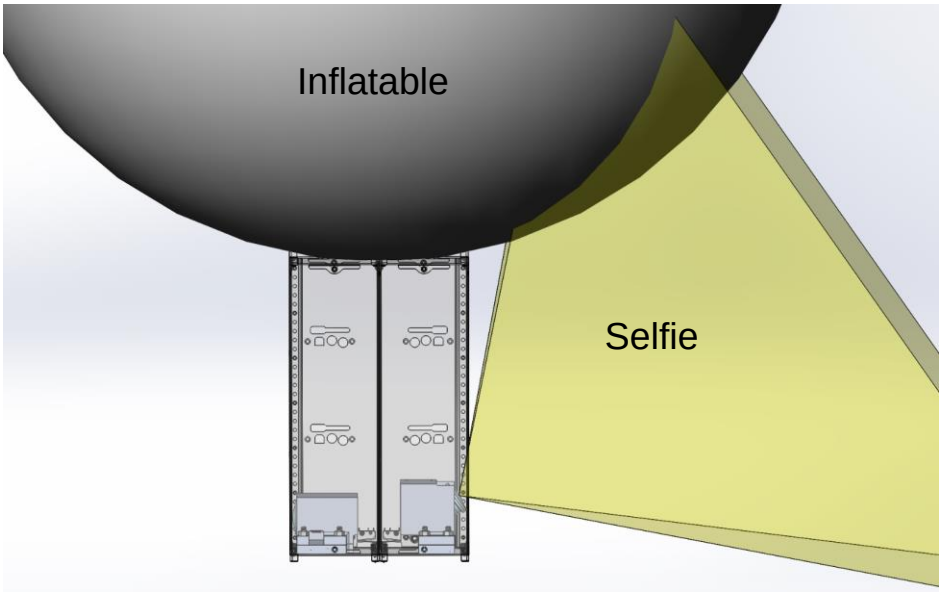


Figure 5.5: CatSat Field of View

6.0 Acceptance Test Results Summary

The acceptance test procedure in its entirety, including filled out data sheets may be found in Appendix A of this report.

During thermal-vacuum test procedure, it was not possible to connect our camera assemblies to a computer to functionally test them while they were sealed inside the chamber. To mitigate this, functional tests were performed before and after sealing the camera assemblies in the thermal-vacuum chamber to verify system functionality. All camera assemblies were fully functional prior to and following thermal-vacuum acceptance testing.

The CatCam vibration acceptance testing (conducted by Hofstadter Analytical Services) put our camera assemblies under 20-2000 Hz random vibrations for at least 2 minutes on each orthogonal axis, and camera functionality was verified before and after testing. Neither camera assembly sustained damage to the camera lens or electronics after testing. The analysis (prepared by Hofstadter Analytical Services) showed that the resonant frequencies for the CatCam camera assemblies was outside the range specified by NASA. The shock acceptance test was ruled a No Test, since further information regarding the launch vehicle is required to determine the MEFE.

All CatCam software acceptance testing pass with the exception of two acceptance tests: Data Rate and Capture Command tests, each ruled as a No Test. There were issues stemming from CatCam compression methods using the Pixelink SDK that prevented testing for this acceptance test. The Capture Command test was ruled as a No Test due to differences between the test equipment (Raspberry Pi) and the actual CatSat computer (GOMSpace Nanomind) - this was a hardware limitation of the test equipment and the acceptance test could not be conducted without the actual CatSat computer. The sponsor has been briefed on these No Test acceptance tests.

7.0 Final Budget

Used On	Part	Part Number	Supplier	Qty	Cost Each ($)	Shipping Cost ($)	Total Cost ($)
Sounding Rocket	Camera	PL-D722CU-BL	Pixelink	1	1095	61	1156
Sounding Rocket	Cinegon 4.8mm Lens	27-1991848	Schneider Optics	1	1521	0	1521
Sounding Rocket	Camera Case	Machined	UA Machining & Welding Center	1	1050	0	1050
Sounding Rocket	Backup Camera Case	Machined	UA Machining & Welding Center	1	1050	0	1050
Sounding Rocket	Raspberry Pi 3 B+	3775	Adafruit	1	35	11.18	46.18
Sounding Rocket	Power Regulator	I15-050-Q12P-C	Digi-Key Electronics	1	32.24	11.63	43.87
Sounding Rocket	M2x0.4mm Thread, 20mm Long Screw	91294A539	McMaster -Carr	1	8.5	0.48	8.98
Sounding Rocket	M2.5x0.45mm Thread, 25mm Long Screw	91294A540	McMaster -Carr	1	10	0.56	10.56
Sounding Rocket	M5x0.8mm Thread, 30mm Long Screw	91294A217	McMaster -Carr	1	6.3	0.35	6.65
Sounding Rocket	M2x0.4mm Thread Locknut	93625A101	McMaster -Carr	1	7.32	0.41	7.73
Sounding Rocket	M2.5x0.45mm Thread Locknut	93625A102	McMaster -Carr	1	10.25	0.57	10.82
Sounding Rocket	M5x0.8mm Thred Locknut	93625A200	McMaster -Carr	1	6.46	0.36	6.82
Sounding Rocket	64GB SanDisk microSDXC	113-8871477-0720247	Amazon	1	12.99	0	12.99
Sounding Rocket	155 mm Flex Cable	PL-CC-08	Pixelink	1	45	0	45
18032	Pixelink SDK	PL-SW-02	Pixelink	1	540	0	540
18032	Camera	PL-D722CU-BL	Pixelink	2	985.5	120.92	2091.92
18032	Camera w/ Housing	PL-D722CU	Pixelink	1	1075.5	107.48	1182.98
18032	Cinegon 4.8mm Lens	27-1991848	Schneider Optics	2	1521		3042
18032	155mm Flex cable	PL-CC-08	Pixelink	2	45	61	151
18032	USB Connection Cable	GSC-03-84761-24D	Gore Aerospace	1	0	0	0
18032	5 Big Balloons-36"	N/A	Peas Shop	1	13.99	0	13.99
18032	CatCam Case	Machined	UA Machining & Welding Center	1	1428.75	0	1428.75
18032	Rasberry Pi 3 B+	3775	Adafruit	1	35	11.18	46.18
18032	2.6" Black Brant II	K-3135	Moscow Rocketry	1	132.95		132.95

18032	Design Day Shirts	N/A	Lunar and Planetary Lab	6	0	0	0
18032	Micro USB Type B Connectors	MP3-MIBV-4-CM	Mouser Electronics	5	2.98	7.99	22.89
18032	Krylon Shimmer Metallic Spray Blue	B00F9LDVJW	Amazon	1	9.45	0	9.45
18032	Krylon Metallic Gold	B000MRUYI4	Amazon	1	4.99	0	4.99
18032	Rust-Oleum Apple Red	B072ZS4HG6	Amazon	1	4.48	0	4.48
18032	Micro USB 3.0 Cable	B00NH13G5A	Amazon	1	5.79	0	5.79
18032	Raspberry Pi Power Supply	B07CVH21NC	Amazon	2	9.99	0	19.98
18032	Passivated 18-8 Stainless Steel Phillips Flat Head Screw	92010A438	McMASTER-CARR	1	7.93	1.22	9.15
18032	18-8 Stainless Steel Hex Nut	91828A251	McMASTER-CARR	1	8.73	1.22	9.95
18032	18-8 Stainless Steel Phillips Flat Head Screw	91771A102	McMASTER-CARR	1	14.43	1.22	15.65
18032	18-8 Stainless Steel Hex Nut	91841A115	McMASTER-CARR	1	7.85	1.22	9.07
18032	316 Stainless Steel Phillips Flat Head Screws	91801A540	McMASTER-CARR	1	13.2	1.22	14.42
18032	Zinc-Plated Steel Hex Nut	90591A265	McMASTER-CARR	1	2.08	1.22	3.3
18032	Vibration Test	N/A	Hofstadter Analytical Services	1	253	0	253
18032	CatCam Design Day Poster	2814	FedEx Office	1	116.99	10.18	127.17

Color	**Paid By**
	LPL
	Senior Design Team 18032

LPL	$9682.45
Senior Design	$4433.21

CatCam Cost Summary

Part	Part Number	Supplier	Qty	Cost Each ($)	Shipping Cost ($)	Total Cost ($)
Camera	PL-D722CU-BL	Pixelink	2	985.5	120.92	2091.92
Cinegon 4.8mm Lens	27-1991848	Schneider Optics	2	1521		3042
USB Connection Cable	GSC-03-84761-24D	Gore Aerospace	2	0	0	0
155mm Flex cable	PL-CC-08	Pixelink	2	45	61	151
Passivated 18-8 Stainless Steel Phillips Flat Head Screw	92010A438	McMASTER-CARR	8	0.32	1.22	3.78
18-8 Stainless Steel Hex Nut	91828A251	McMASTER-CARR	8	0.0873	1.22	1.9184
18-8 Stainless Steel Phillips Flat Head Screw	91771A102	McMASTER-CARR	8	0.1443	1.22	2.3744
18-8 Stainless Steel Hex Nut	91841A115	McMASTER-CARR	8	0.0785	1.22	1.848
316 Stainless Steel Phillips Flat Head Screws	91801A540	McMASTER-CARR	8	0.132	1.22	2.276
Zinc-Plated Steel Hex Nut	90591A265	McMASTER-CARR	8	0.0208	1.22	1.3864
CatCam Case	Machined	UA Machining & Welding Center	2	1428.75	0	1428.75

Total	$6727.2532
Per Camera	**$3363.6266**

8.0 Lessons Learned

In doing this project, the lessons learned by our team were to:

- Iterate early/often: in the design process, it is essential to come up with designs early and iterate often with feedback from the sponsor/customer.
- Avoid feature creep: we learnt to focus on our main requirements first, before going above and beyond on any certain aspect of the project.
- Keep sponsor on track: regular meetings with our sponsor helped us stay in touch with the project as a whole and staying up to date with sponsor expectations, change in requirements, etc.
- Test/Analysis: it is important to conduct tests/analyses on each iteration of the device to make sure that no unforeseen events/failures occur
- Theoretical expectations vs physical reality: in engineering, physical realities/tests may go against what was theoretically expected. Physical tests and experience are essential and offer the full picture beyond theoretical expectations and analyses

Appendix A: Acceptance Test Procedures & Results

1.0 CatCam Thermal-Vacuum Acceptance Tests

1.1 Introduction

This procedure outlines the acceptance tests to be performed on the CatCam camera subassembly using a thermal-vacuum chamber. These tests verify the ability of the CatCam camera subassembly to operate under the thermal conditions expected in orbit (between -10℃ - +60℃), the ability of the CatCam camera subassembly to operate in a vacuum environment, and the minimization of outgas over the system life cycle.

1.2 Referenced Documents

CatCam System Requirements Document, Rev 1, 10/20/2018
NASA-STD-7002, Rev B, 6/6/2018
Standard Test Method for Total Mass Loss and Collected Volatile Materials from Outgassing in a Vacuum , E595-15

1.3 Required Equipment

Description	Part No.	Accuracy	Qty.
Camera CCA	PL-D722CU	N/A	2
Camera Lenses	HF6XA-5M	N/A	2
Camera Enclosure	N/A	N/A	2
Thermal-vacuum chamber	N/A	TBD	1
Scientific Scale	N/A	TBD	1
Stopwatch	N/A	.1 sec	1
CatCam Test Computer + Control Software	N/A	N/A	1

1.4 Table of Tests

Test #	Test Description	Requirement
1-01	Thermal Environment	-10℃ - +60℃
1-02	Vacuum Environment	< 10^{-4} torr
1-03	Outgas Environment	<1% Total Mass Loss (TML)

1.5 Step by Step Procedure

1. Install thermo-couples at critical monitoring locations.
2. Assemble UUT (camera CCA, camera enclosure, and camera lens).
3. Record initial UUT weight.
4. Boot CamCam test computer and camera control software. Read inputs from thermo-couples and verify calibration.
5. Clamp UUT down in the thermal vacuum chamber.
6. Take initial temperature reading of the UUT prior to sealing the chamber.
7. Power on thermal vacuum chamber, cycle temperature to upper limit to "bake" away volatiles. Monitor thermocouples for anomalous behavior.
8. (1-02) Seal the thermal vacuum chamber, set the chamber pressure to the at most required 10^{-4} torr.
9. Record minimum pressure achieved.
10. (1-01) Cycle chamber temperatures between the required minimum (-10℃) and maximum (+60℃) temperatures for not less than 5 cycles.
11. Record minimum and maximum temperatures reached during these cycles.
12. Allow heating/cooling plate to return to room temperature. Re-pressurize, unseal chamber.
13. Remove UUT from the thermal vacuum chamber.
    CAUTION: UUT may be too hot/cold to handle without protective equipment - use PPE when handling the UUT to avoid injury.
14. Connect UUT to CatCam computer, verify power-on and connection. Record results.
15. Replace and clamp UUT down in thermal vacuum chamber.
16. (1-03) Seal the thermal vacuum chamber, set the chamber pressure to the at most required 10^{-4} torr, cycle chamber temperature to 60℃ for 24 hours.
17. Cycle chamber temperature to 23℃, let cool. Re-pressurize and unseal chamber.
18. Record final UUT weight.
19. Calculate total mass loss (TML)
20. Repeat test for all camera assemblies.

2.0 CatCam Vibroacoustic Acceptance Tests

2.1 Introduction

This procedure outlines the acceptance tests to be performed on the CatCam camera subassembly using a vibration table. These tests verify the ability of the CatCam camera subassembly to operate under the random vibration profile expected in orbit, and the ability of the CatCam camera subassembly to survive the vibration and shock experienced during initial launch into orbit.

2.2 Referenced Documents

CatCam System Requirements Document, Rev 1, 10/20/2018
NASA-STD-7001, Rev B, 11/7/2017
NASA-STD-7002, Rev B, 6/6/2018

2.3 Required Equipment

Description	**Part No.**	**Accuracy**	**Qty.**
Camera CCA	PL-D722CU	N/A	2
Camera Lenses	HF6XA-5M	N/A	2
Camera Enclosure	N/A	N/A	2
Vibration Table	N/A	TBD	1
Stopwatch	N/A	.1 sec	1
CatCam Test Computer + Control Software	N/A	N/A	1

2.4 Table of Tests

Test #	**Test Description**	**Requirement**
2-01	Vibration Environment	2 minutes on each orthogonal axis, repeated 3 times. Forcing function: (TBD)
2-02	Shock Environment	Shock (TBD) applied at minimum once to each orthogonal axis

2.5 Step by Step Procedure

1. Assemble UUT (camera CCA, camera enclosure, and camera lens).

2. Boot CatCam test computer and camera control software.
3. Affix UUT to vibration table on the desired orthogonal axis, record which axis is being tested.
    3.1. (2-01) Program vibration table with the expected power spectral density (PSD) of vibration, begin vibration test.
    3.2. After at least 2 minutes (TBR) has elapsed, end vibration. Record elapsed time and vibration frequency.
    3.3. Connect UUT to CatCam test computer, verify power-on, connection, and clear image capture. Record results. Disconnect UUT from CatCam test computer when finished.
    3.4. Visually inspect UUT for obvious signs of damage near camera lens threads, CCA mounting holes, and enclosure mounting holes. Record results.
    3.5. Repeat steps 3-3.4 until the current orthogonal axis has been vibration tested at least 3 times, recording results as necessary.
    3.6. (2-02) Program vibration table with the desired level of shock (TBD), and apply shock to UUT. Record level of shock applied to camera assembly.
    3.7. Repeat steps 3.3-3.4, recording results as necessary.
4. Rotate UUT to next orthogonal axis, affix to vibration table.
5. Repeat steps 3-4 until all orthogonal axes have been tested, recording results as necessary.

3.0 CatCam Control Software Acceptance Tests

3.1 Introduction

This procedure outlines the acceptance tests to be performed on the CatCam control software. These tests verify the ability of the CatCam control software to communicate with the CatSat computer, control each camera independently, capture images of the required quality, compress captured images, and send captured images to the CatSat computer at the desired rate with minimal loss.

3.2 Referenced Documents

CatCam System Requirements Document, Rev 1, 10/20/2018

3.3 Required Equipment

Description	Part No.	Accuracy	Qty.
Camera CCA	PL-D722CU	N/A	2
Camera Lenses	HF6XA-5M	N/A	2
Camera Enclosure	N/A	N/A	2
CatCam Test Computer + Control Software	N/A	N/A	1

3.4 Table of Tests

Test #	Test Description	Requirement
3-01	Data Interface	Send/Receive data from CatSat Computer
3-02	Camera Control	Independently control each camera
3-03	Image Compression	Compress images to a 32:1 ratio
3-04	Data Transfer	Minimize data loss
3-05	Data Rate	40 Mbps
3-06	Selfie Resolution	1920 x 1200 pixels
3-07	Earth Resolution	HD quality video
3-08	Capture Command	Power-on camera & capture image/video

3.5 Step by Step Procedure

1. Assemble UUT (camera CCA, camera enclosure, and camera lens) for both cameras.
2. Connect both UUT's to the CatCam test computer.
3. From the CatCam test computer, send a capture command from the control software to each UUT.
    3.1. (3-01, 3-02, 3-08) Verify each UUT powers on and captures an image/video within a reasonable amount of seconds of the command being sent. Record results (PASS/FAIL) for each.
4. (3-06) Verify that the image captured by the Selfie camera UUT is at least 1920 x 1200 pixels. Record resolution.
5. (3-07) Verify that the video captured by the Earth camera UUT is at least HD video quality. Record video resolution and frames per second.
6. (3-03) For the output data from each UUT, verify that the data has been compressed to a 32:1 ratio. Record file size for each.
7. (3-04) Un-compress the compressed image/video data from step 6 for each UUT, verify that the uncompressed image/video meets the required quality parameters. Record image resolution and video quality.
8. (3-05) With a set of images with a known file size, use these images as an input to the control software image compression function(s), and record the time elapsed until the compress image set has been passed through the control software's output interface.
    8.1. Record total input data set size
    8.2. Record time elapsed
    8.3. Calculate and record data transfer rate.

4.0 CatCam System Acceptance Tests

4.1 Introduction

This procedure outlines the acceptance tests to be performed on the CatCam system. These tests verify that placement of the camera assemblies within the CatSat frame will allow each camera to meet their required image frame. It can use either the CatSat frame or a 3D-printed replica. In testing video taken from the Earth-facing camera, video of the surrounding lab environment will substitute video of the Earth from orbit.

4.2 Referenced Documents

CatCam System Requirements Document, Rev 1, 10/20/2018

4.3 Required Equipment

Description	Part No.	Accuracy	Qty.
Camera CCA	PL-D722CU	N/A	2
Camera Lenses	HF6XA-5M	N/A	2
Camera Enclosure	N/A	N/A	2
CatCam Test Computer + Control Software	N/A	N/A	1
CatSat Frame	N/A	TBD	1

4.4 Table of Tests

Test #	Test Description	Requirement
4-01	Selfie Camera Coverage	Capture wide-angle images of the inflatable antenna
4-02	Earth Camera Coverage	Capture HD video of the Earth's surface

4.5 Step by Step Instructions

1. Assemble UUT (camera CCA, camera enclosure, and camera lens) for both cameras.
2. Place each UUT into its own designated position (Earth-facing and Selfie)
3. Connect both UUT's to the CatCam test computer.
4. From the CatCam test computer, send a capture command from the control software to each UUT.
    4.1. (4-01) For the image captured from the Selfie UUT, verify that the inflatable antenna is adequately covered with minimum obstruction (PASS/FAIL). Record results.
    4.2. (4-02) For the video captured from the Earth UUT, verify that the surrounding lab environment is captured without obstruction (PASS/FAIL). Record results.

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
1.0

Analysis Referenced (for verification by T/A): N/A

Name of Test:
Thermal Environment Test

Unit Under Test (UUT)
Name: CatCam Camera Assembly
Part Number: TBD
Serial Number:

Results (Pass/Fail):		Date of Test:	
PASS		4/18/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Min Temp: Max Temp: +60°C # Cycles: 5 Duration: 24 hours	>-10°C, <+60°C	N/A	N/A

Computations (Include analyses results, if any):

Plot data and attach to sheet.

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
1.0

Analysis Referenced (for verification by T/A):

Name of Test:
Vacuum Environment Test

Unit Under Test (UUT)
Name: CatCam Camera System
Part Number: TBD
Serial Number:

Results (Pass/Fail):		Date of Test:	
PASS		4/18/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Minimum pressure: 10^{-4} torr Duration: 24 hours	$<10^{-4}$ torr	N/A	N/A

Computations (Include analyses results, if any):

Plot data and attach to sheet.

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
1.0

Analysis Referenced (for verification by T/A):

Name of Test:
Outgas Environment Test

Unit Under Test (UUT)
Name CatCam Camera System
Part Number TBD
Serial Number

Results (Pass/Fail):	Date of Test:
PASS	4/18/2019

Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Total Mass Loss (TML): EF: 0.0113% Self: 0.0130% USB: 0.0188%	TML < 1%	N/A	1%

Computations (Include analyses results, if any):
Initial UUT Weight (g): EF: 463.2588; Self: 418.0414; USB: 22.8783

Final UUT Weight (g): EF: 463.2063; Self: 417.9872; USB: 22.8740

TML(%) = (Initial Weight - Final Weight)/(Initial Weight) *100

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
2.0

Analysis Referenced (for verification by T/A):

Name of Test:
Vibration Environment Test

Unit Under Test (UUT)
Name: CatCam Camera Assembly
Part Number: TBD
Serial Number:

Results (Pass/Fail):		Date of Test:	
PASS		4/17/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Vibration PSD: 20-2000Hz @ >6G Duration: >2 min./axis Vibe/Axis: 1	2 minutes per orthogonal axis, <2000Hz	N/A	N/A

Computations (Include analyses results, if any):

Power spectral density (PSD) of vibration:

See Vibration Analysis (prepared by Hofstadter Analytical)

Plot data and attach to sheet.

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
2.0

Analysis Referenced (for verification by T/A):

Name of Test:
Shock Environment Test

Unit Under Test (UUT)
Name
Part Number
Serial Number

Results (Pass/Fail):		Date of Test:	
FAIL		NO TEST	
Recording of Test Measurement: Force applied: Shock/axis:	Requirement (SRD, with Tolerances): Shock force (TBD) applied ≥1 time per orthogonal axis.	Test Equipment Error: N/A	Adjusted Test Limit: N/A

Computations (Include analyses results, if any):

Plot data and attach to sheet.

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Data Interface Test

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Command sent: Image capture Command received: Image capture	Successfully send/receive data from/to CatCam control software.	N/A	N/A

Computations (Include analyses results, if any):

N/A

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Camera Control

Unit Under Test (UUT)
Name: CatSam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Earth Cam Control: Yes Selfie Cam Control: Yes	Control each camera independently	N/A	N/A

Computations (Include analyses results, if any):

N/A

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Image Compression

Unit Under Test (UUT)
Name: Camera Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Compressed size rel. to uncompressed (%): 3.125%	3.125% Original size	+/- 2.5%	5.625% Original size (TBR)

Computations (Include analyses results, if any):

Uncompressed file size (MB): 129.6 MB

Compressed file size (MB): 4.05 MB

$$\frac{Compressed\ file\ size\ (MB)}{Uncompressed\ file\ size\ (MB)} = 3.125\%$$

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Data Transfer

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
% data loss: 0	<0.5% data loss	.01%	<0.6% data loss

Computations (Include analyses results, if any):

Sent image size (uncompressed, MB): 0.864 MB

Sent image resolution: 1920x1200

Received image size (uncompressed, MB): 0.864

Received image resolution: 1920x1200

$$\frac{Sent\ image\ size\ (MB)}{Received\ image\ size\ (MB)} =$$

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Data Rate Test

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
FAIL		NO TEST	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Data Rate (Mbps):	>40.0 Mbps	.2 Mbps	>39.8 Mbps

Computations (Include analyses results, if any):

Image file size (Mb):

NOTE $Megabits = \frac{Megabytes}{8}$

Time to send/receive (s):

$$Data\ Rate = \frac{Image\ file\ size\ (Mb)}{Time\ to\ send\ (s)}$$

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):
N/A

Name of Test:
Selfie Resolution Test

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Selfie Image Resolution: 1920x1200	1920 x 1200 pixels	.05%	1910 x 1194 pixels

Computations (Include analyses results, if any):

Horizontal pixel count: 1920

Vertical pixel count: 1200

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Earth Resolution Test

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Video Resolution: 1920x1200	720p (1280 x 720)	.05%	1274 x 716 pixels
Fps: 30	30 fps	1%	27 fps

Computations (Include analyses results, if any):

Horizontal pixel count: 1920

Vertical pixel count: 1200

Total # frames: 150

Duration (s): 5

$$Frames\ per\ second\ (fps) = \frac{Total\ \#\ frames}{Duration\ (s)}$$

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
3.0

Analysis Referenced (for verification by T/A):

Name of Test:
Capture Command Test

Unit Under Test (UUT)
Name: CatCam Control Software
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
FAIL		NO TEST	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Camera powered? Image/video captured?	Power on camera Capture image/video	N/A	N/A

Computations (Include analyses results, if any):

N/A

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
4.0

Analysis Referenced (for verification by T/A):
Camera Coverage Analysis

Name of Test:
Selfie Camera Coverage Test

Unit Under Test (UUT)
Name: CatCam System
Part Number: N/A
Serial Number:

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Inflatable captured? Yes % Unobstructed FOV 100%	Capture inflatable antenna Minimize obstructions	N/A	N/A

Computations (Include analyses results, if any):

Horizontal pixel count: 1920

Vertical pixel count: 1200

$$Total\ pixel\ area = Horizontal\ count * Vertical\ count:$$

Area unobstructed: 1920x1200

$$\%\ Unobstructed\ FOV = \frac{Area\ unobstructed}{Total\ pixel\ area}:$$

Signatures
Tester:_____
Customer:_____

Acceptance Test Data Sheet

Referenced ATP Paragraph Number:
4.0

Analysis Referenced (for verification by T/A):
Camera Coverage Analysis

Name of Test:
Earth Camera Coverage Test

Unit Under Test (UUT)
Name: CatCam System
Part Number: N/A
Serial Number: N/A

Results (Pass/Fail):		Date of Test:	
PASS		4/1/2019	
Recording of Test Measurement:	**Requirement (SRD, with Tolerances):**	**Test Equipment Error:**	**Adjusted Test Limit:**
Lab environment captured? Yes % Unobstructed FOV: 100	Capture Earth surface Minimize obstructions	N/A	N/A

Computations (Include analyses results, if any):

Horizontal pixel count: 1920

Vertical pixel count: 1200

$Total\ pixel\ area = Horizontal\ count * Vertical\ count$:

Area unobstructed: 1920x1200

$\%\ Unobstructed\ FOV = \frac{Area\ unobstructed}{Total\ pixel\ area}$:

Signatures
Tester:_____
Customer:_____

Appendix B: Software Development Document

1.0 Scope

1.1 Identification

This document applies to the CatCam system and control software.

1.2 System Overview

The Computer Software Configuration Items (CSCI) will control both cameras in the CatCam system, acquire images from the cameras, compress the images so that they can be downlinked through the CatSat communication system and then decompress the images to create a continuous full-image video. This software is being developed by team 18032 for Senior Design 2019.

1.3 Document Overview

The purpose of this document is to describe the overall architecture, interfaces and design elements of the CatCam software.

2.0 Referenced Documents

CatCam System Requirements Document, Rev 1, 10/20/2018

3.0 CSCI-Wide Design Decisions

3.1 Inputs, Outputs and Interfaces

The inputs of the image acquisition system are camera controls and parameters, the input of the image compression system is uncompressed full image video, and the input of the image decompression system is compressed full image video files. The outputs of the image acquisition system are part-images and full-image video, the outputs of the image compression system are compressed full-image video files cadenced at three seconds, and the output of the image decompression system is continuous uncompressed full-image video. The system will interface with the onboard spacecraft computer to both receive commands and send compressed files to the ground station.

3.2 Performance Characteristics

In response to the camera controls and parameters input to the image acquisition system, the CSCIs will execute the selected commands on the camera. The response time of this action will be real-time. The physical system will be a USB connected to the CatSat spacecraft computer. The CSCIs will not allow readout video times over three seconds and will not allow video or images to be deleted from local memory until a certain amount of time has passed.

In response to the compressed full-image video the CSCIs will uncompress the three second videos and then put them together to create a continuous video stream. The response time of this action will be within a few minutes of starting. The physical system will be a linux computer with C software. The CSCIs will not allow video or images to be deleted without multiple confirmations.

3.3 Databases and Files

The video will be compressed in a 32:1 format and cadenced at three second intervals. Upon receipt of the video, the CSCIs will uncompress the video into a specific format.

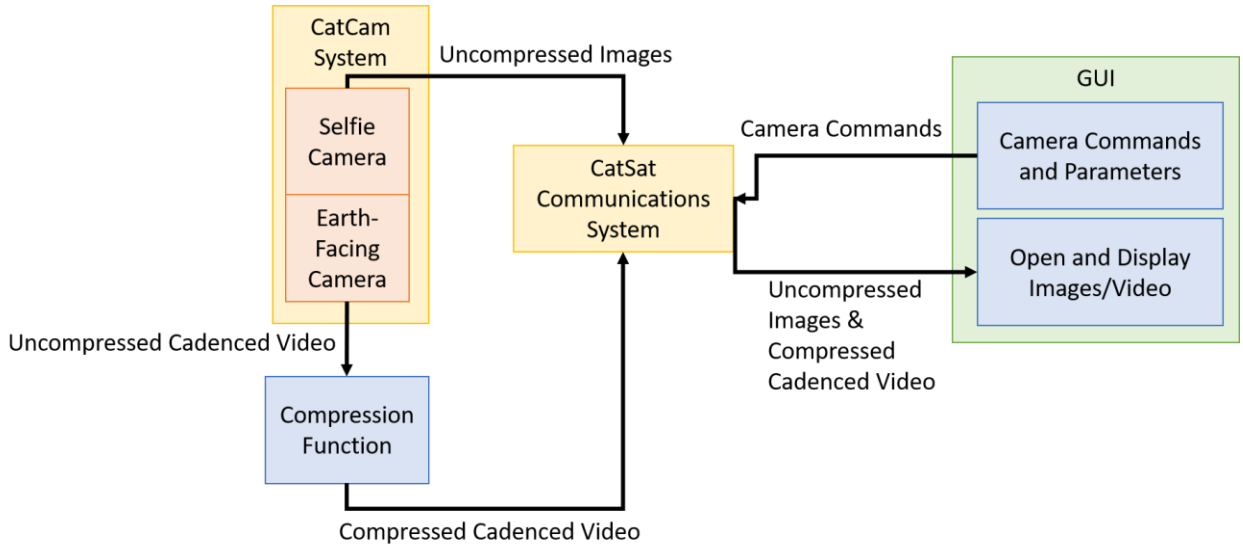
3.4 Security Requirements

No encryption is necessary.

3.5 Requirement Satisfaction

The CSCIs meet all designed requirements.

4.0 CSCI Architectural Design



4.1. CSCI Component: Camera Commands

4.1.1 Identification

This CSC controls both the Selfie Camera and the Earth-Facing Camera. This CSC will accept a text file with camera parameters and will output camera commands.

4.1.2 Purpose

The purpose of this CSC is to control both Cameras of the CatCam System, including exposure times, bit depth and frame per second.

4.1.3 Status

This CSC has been planned and designed but not yet created.

4.1.4 Planned Computer Resources

This CSC will use receive a text document from the User and will output a series of commands to the CatCam communication system.

4.1.5 Library

This CSC will use the Pixelink SDK library for C software.

4.2 Concept of Execution

The User will enter a text file of camera parameters. The camera control software will take the camera parameters and output camera commands to the CatSat communication system. The CatSat communication system receives camera commands and outputs them to both the Selfie Camera and Earth-Facing Camera. The Selfie Camera receives the camera commands and outputs uncompressed part-images to the CatSat communication system. The Earth-Facing Camera receives camera commands and outputs uncompressed cadenced video to the compression function. The compression function receives uncompressed cadenced video from the Earth-Facing Camera and outputs compressed cadenced video to the CatCam communication system. The CatCam communication system receives uncompressed part-images and compressed cadenced video and outputs the same inputs to the GUI image and video display. The GUI image and video display receives uncompressed part-images and compressed cadenced video and outputs uncompressed part-images and uncompressed continuous video.

4.3 Interface Design

4.3.1 Identification and Diagrams

The CatCam system will interface with the compression software and the CatSat communication system. The CatSat communication system will interface with the CatCam system, the compression function and the GUI.

4.3.2 Priority

All interfaces are important and are executed in a circular format.

4.3.3 Type

There are Earth to Spacecraft interfaces, Earth to Earth interfaces, and Spacecraft to Spacecraft interfaces.

4.3.4 Individual Characteristics

The Earth to Spacecraft interfaces will be the most difficult to achieve, so these will be done the least frequently.

4.3.5 Assembly Characteristics

The interfaces will be assembled and tested prior to launch.

4.3.6 Communication Characteristics

The interfaces will communicate effectively through digital processing.

4.3.7 Protocol Characteristics

The protocols used will be USB 3.0 and CubeSat protocols.

5.0 CSCI Detailed Design

The Compression Function will use compression commands to execute. The camera commands will use the Pixelink library to execute. The open and display software will use uncompression techniques to operate. The interface between the GUI and CatSat communication system will only be allowed to operate during flyovers of the spacecraft above the receiving station(s). The CSCIs will be written in the C language.

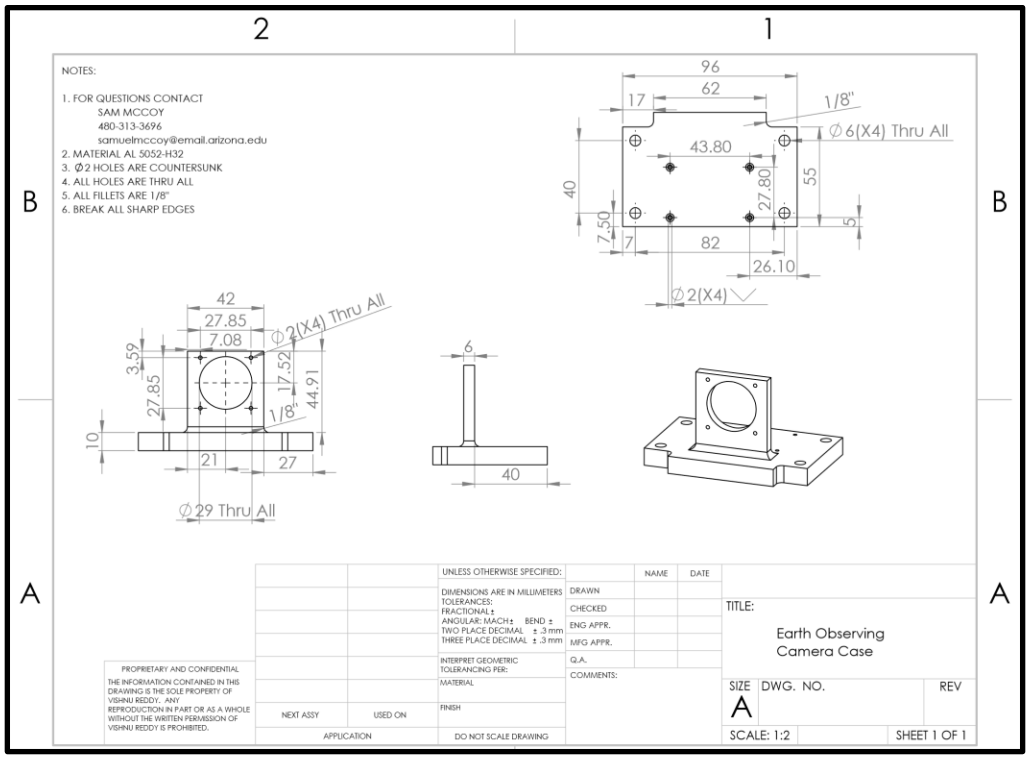
6.0 Requirement Traceability

The requirements in the following table have been traced down to the Camera Commands CSCI. All requirements are verified at the CSCI level.

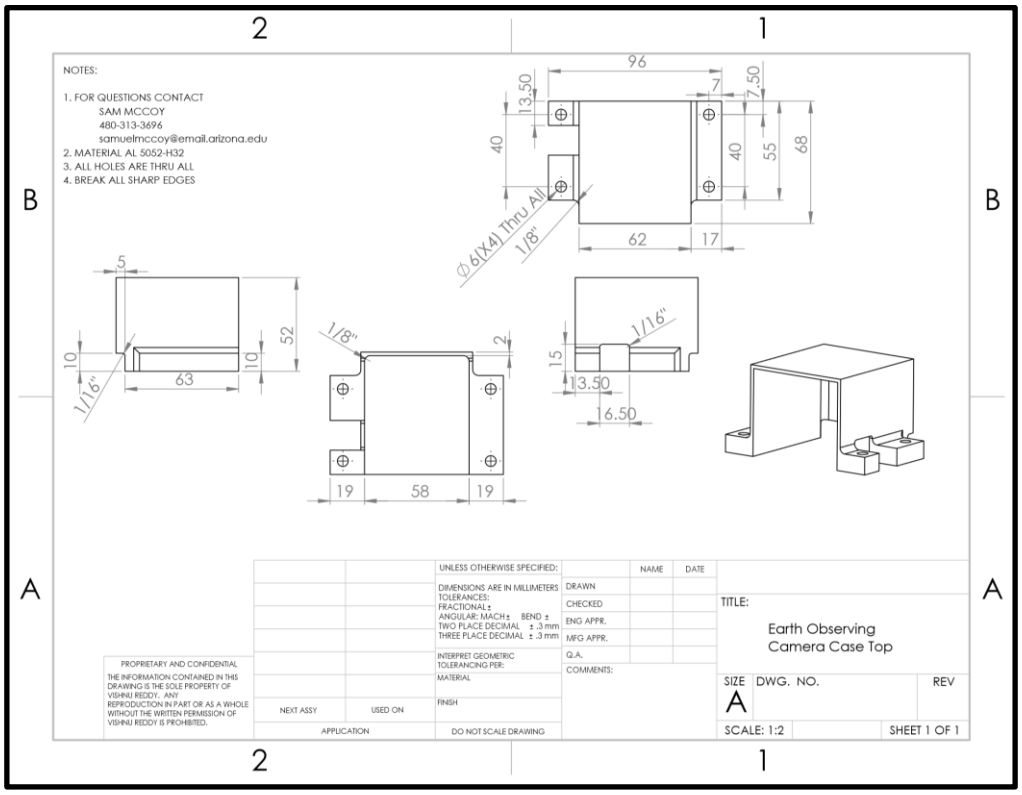
Requirement	VM
The CatCam software shall be compatible with the CatSat computer specifications: GOMspace NanoMind z7000, linux kernel.	D
The CatCam software shall independently control each camera: “Earth-facing” (Camera 1) and “Selfie” (Camera 2).	T
The CatCam software shall compress data to the size specified by the CatSat system designers (TBD).	T
The CatCam system software shall communicate directly with the CatSat internal computer.	T

Appendix C: Drawings

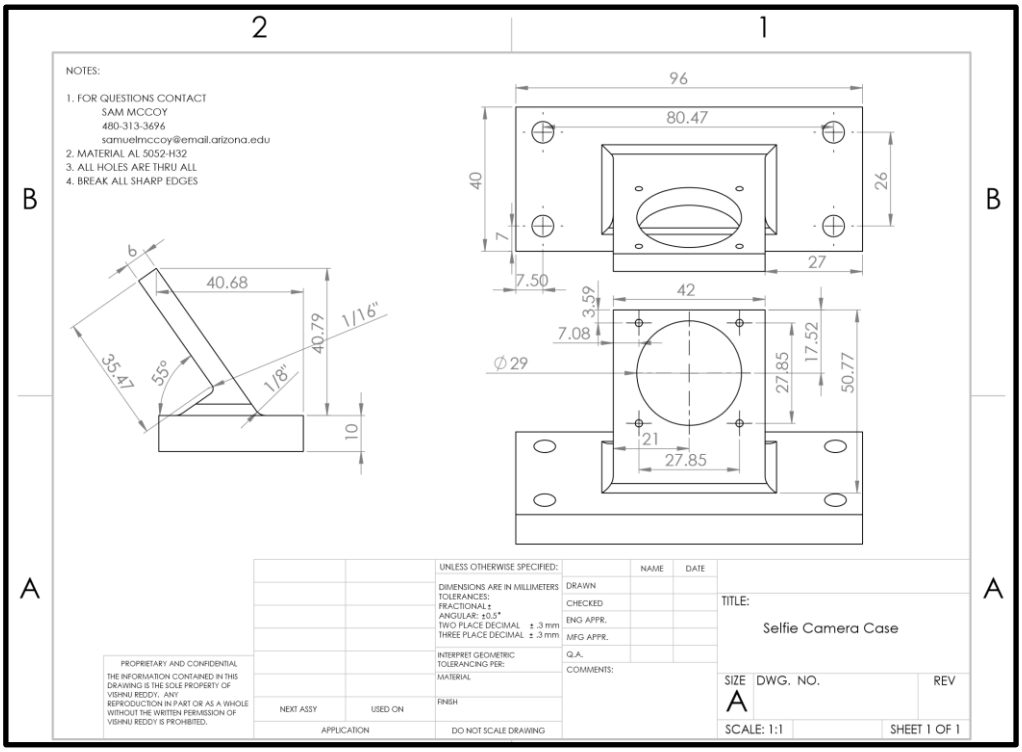
A summary of drawings will be provided in this appendix. The drawings files (PDF format) will be submitted separately with the final report.



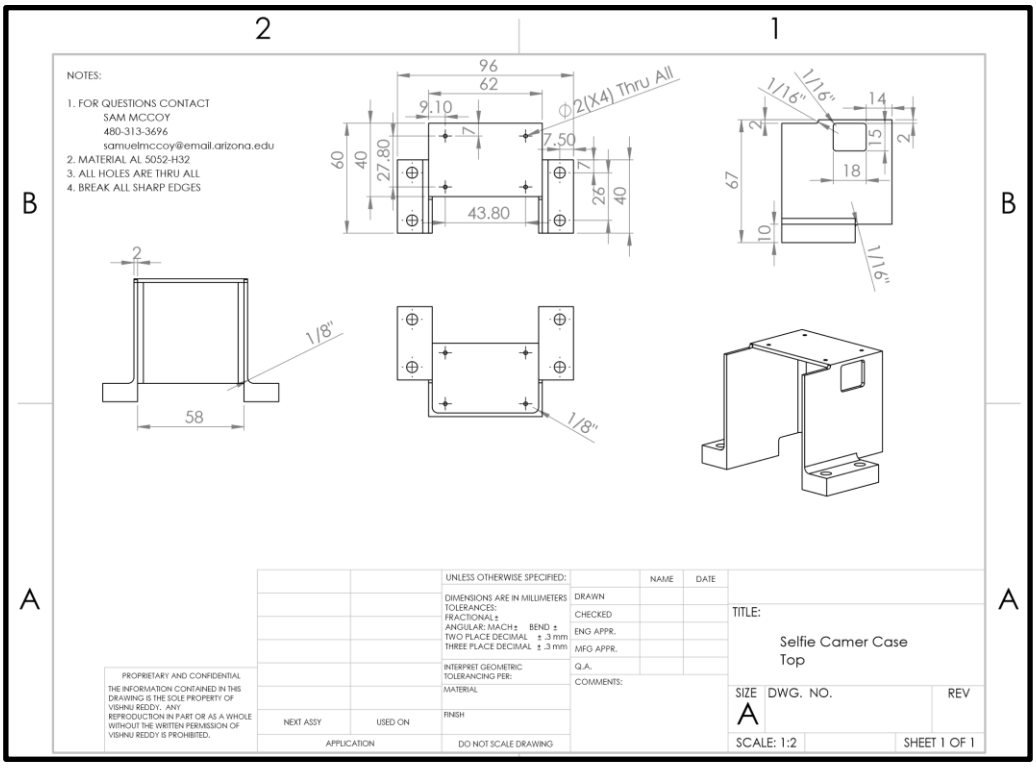
Earth Observing Camera Case: Base Drawing



Earth Observing Camera Case: Top Drawing



Selfie Camera Case: Base Drawing



Selfie Camera Case Top: Drawing

Appendix D: System Requirements

4.0 System Requirements

4.1 Interface Requirements

4.1.1 [SR-001]: The CatCam system shall mount to the CatSat frame IAW CatSat drawing (TBD)[1].

4.1.2 [SR-002]: The CatCam system shall electrically interface with the CatSat system.

4.1.3 [SR-003]: The CatCam system shall transmit and receive data from the CatSat computer.

4.2 Environment Requirements

4.2.1 [SR-004]: The CatCam system shall operate within a minimum temperature range of -10℃ to 60℃ (TBD)[2].

4.2.2 [SR-005]: The CatCam system shall comply with thermal-vacuum environment standards set forth by NASA, IAW NASA-STD-7002B.

4.2.3 [SR-006]: The CatCam system shall comply with vibroacoustic standards set forth by NASA, IAW NASA-STD-7001B.

4.2.4 [SR-007]: The CatCam system shall comply with mechanical shock standards set forth by NASA, IAW NASA-STD-7002B.

4.2.5 [SR-008]: The CatCam system shall minimize the amount of outgassing over the system life cycle.

4.3 Customer Constraints

4.3.1 [SR-009]: The CatCam system shall be 10.0cm x 10.0cm x 5.0cm at maximum.

4.3.2 [SR-010]: The CatCam system shall draw 1.4W from the CatSat power supply at maximum.

4.3.3 [SR-011]: The CatCam system shall weigh 0.45kg at maximum.

4.3.4 [SR-012]: The CatCam system shall cost $10,000.00 at maximum.

4.3.5 [SR-013]: The CatCam system shall utilize two Pixelink PL-DU722CU cameras.

4.4 Software Requirements

4.4.1 [SR-014]: The CatCam software shall be compatible with the CatSat computer specifications: GOMspace NanoMind z7000, linux kernel.

4.4.2 [SR-015]: The CatCam software shall independently control each camera: “Earth-facing” (Camera 1) and “Selfie” (Camera 2).

4.4.3 [SR-017]: The CatCam software shall compress data to the size specified by the CatSat system designers [2].

4.4.4 [SR-018] The CatCam system software shall communicate directly with the CatSat internal computer.

4.5 Performance Requirements

4.5.1 [SR-019]: The CatCam system shall transfer data at a rate of 40Mbps at minimum.

4.5.2 [SR-020]: The CatCam “Selfie” camera shall capture images at a maximum resolution of 1920x1200 pixels.

4.5.3 [SR-021]: The CatCam “Selfie” camera shall be aligned to capture wide-angle images of the CatSat inflatable antenna.

4.5.4 [SR-022]: The CatCam “Earth-facing” camera shall capture video at an HD resolution.

4.5.5 [SR-023]: The CatCam “Earth-facing” camera shall be aligned to capture video of the Earth’s surface [3].

4.5.6 [SR-024] The CatCam shall power on and capture video when a command is received from the CatSat main computer.

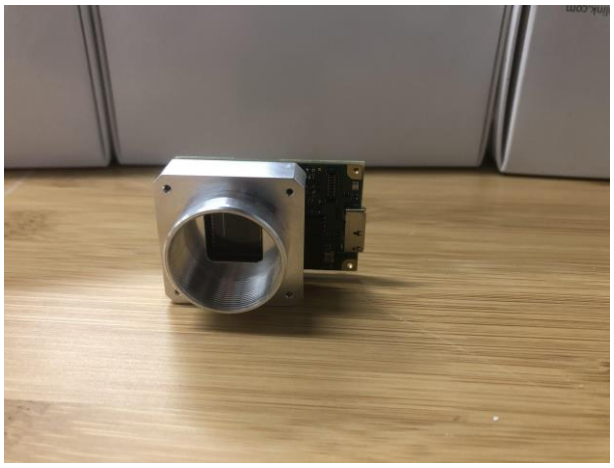
4.5.7 [SR-025]: The CatCam “Earth-facing” and “Selfie” cameras shall each be positioned to eliminate obstruction to their fields of view.

Appendix E: CatCam User Manual

Pixelink PL-D722CU-BL

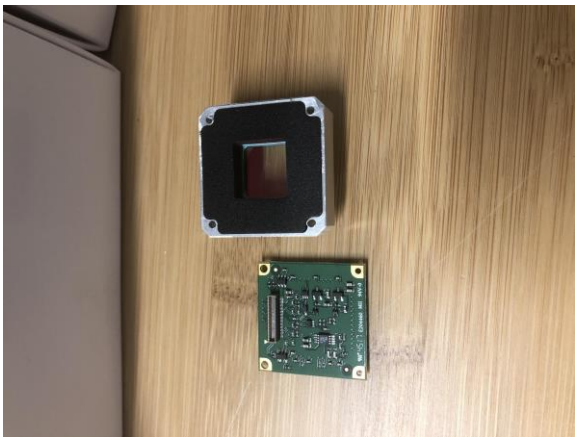
Open the camera box to ensure the Pixelink camera is board-level and comes in packaging similar to the image below:

Take the camera out of the package and remove all screws on the CCA board (back camera board) seen below:

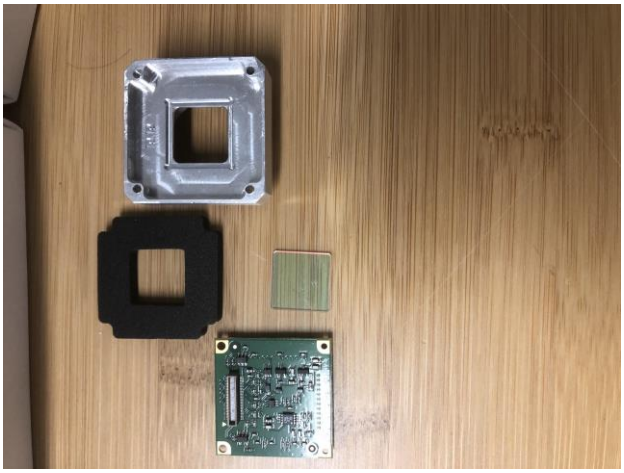


Next, remove the CCA board (back camera board) from the front camera board. Then remove the sensor attachment board so that only the sensor board, the one with the C-mount, is left.

Unscrew the four screws connecting the sensor board and C-mount and remove the sensor board from the C-mount:

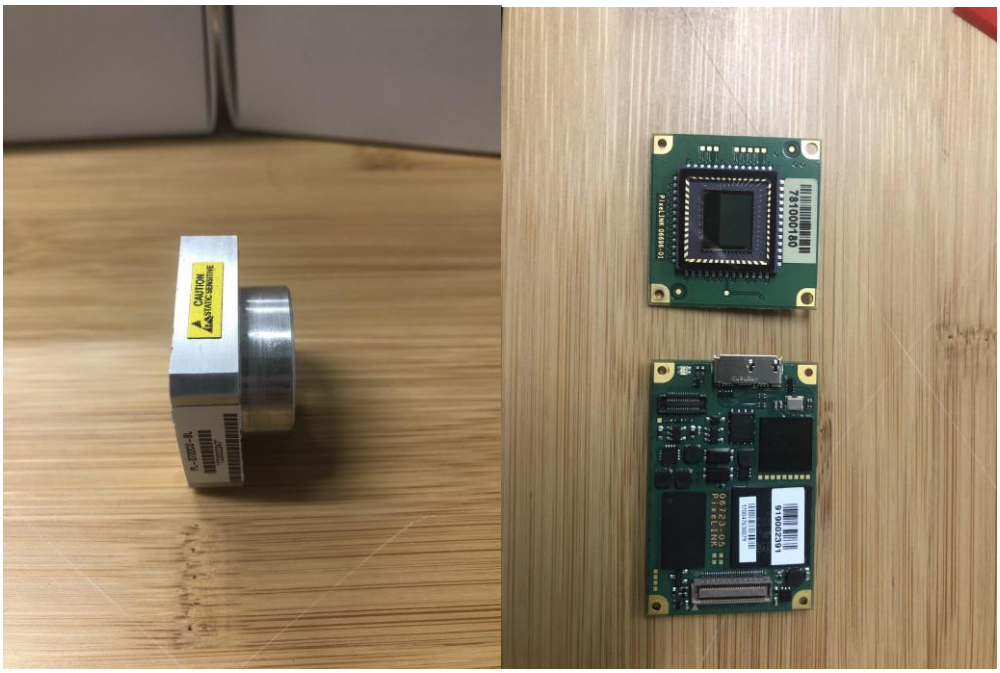


Remove black foam and glass plate from C-mount.

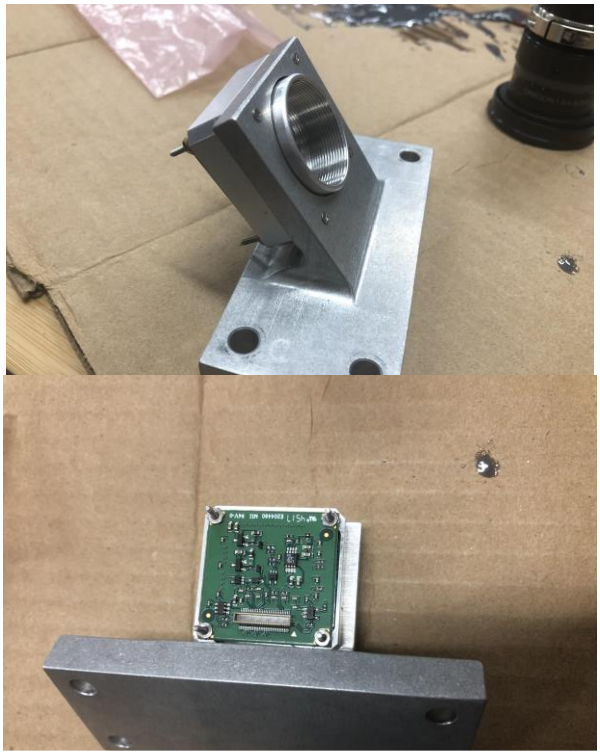


Gather the C-mount (1), sensor board (2), and CCA board(3). The black foam, glass plate, sensor attachment board, nuts, bolts, and spacers can all be discarded.

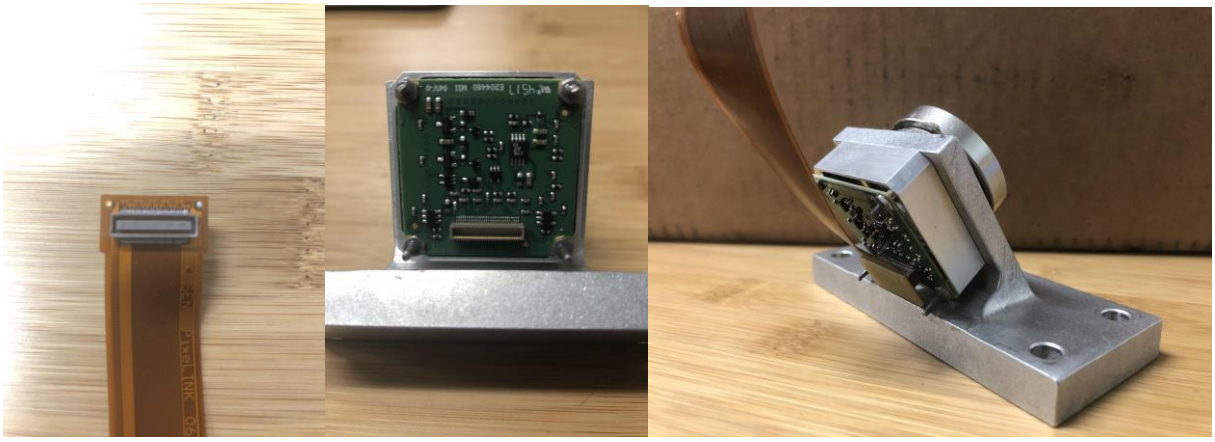
Remove the stickers from the camera mount, sensor board, and CCA board.



Attach the sensor board (2) and C-mount (1) to the bottom camera case with four 0-80 nuts and bolts.

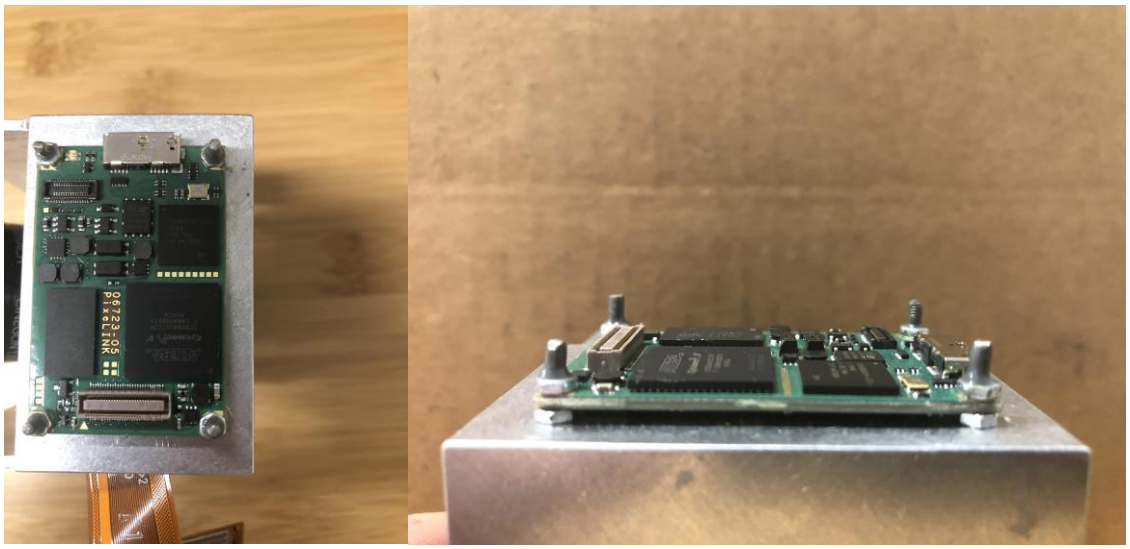


Attach Pixelink 155mm Flex Cable (4) to sensor board. Make sure to align arrows correctly as seen below:



Slide unattached end of Pixelink 155mm Flex Cable (4) through the hole in the top camera case. Then attach top and bottom camera case with four M6 nuts and bolts.

Attach CCA board (3) to the top camera case using four M2 nuts and bolts. Place one M2 nut between case and board and one between board and end of bolt. This was used in order to act like a spacer.



Attach available end of Pixelink 155mm Flex Cable (4) to the CCA board (3). Make sure to align arrows correctly.

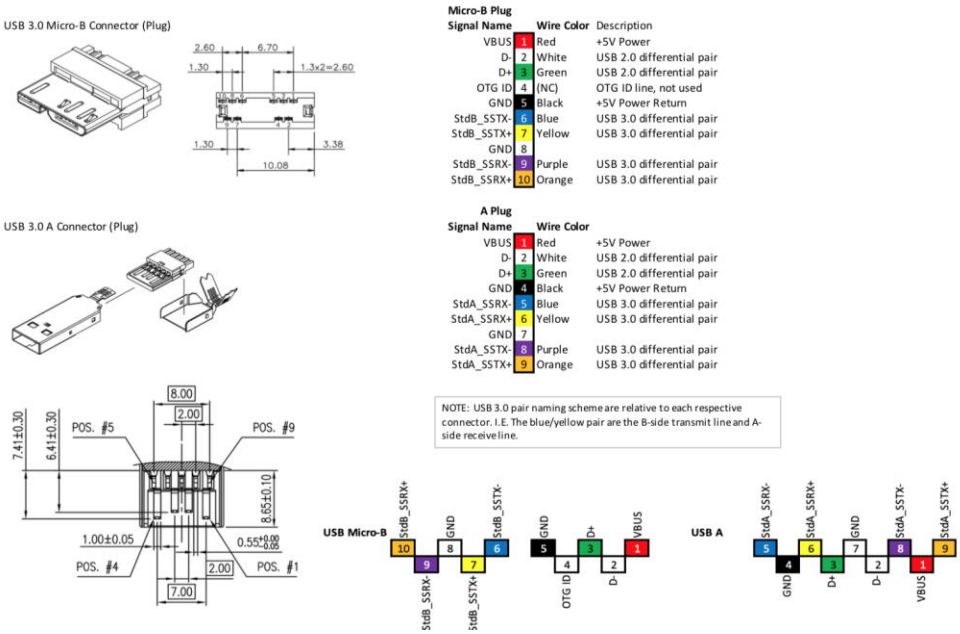
Attach Cinegon 4.8mm Lens (5) to C-mount (1).

Note: Attachment of Earth Facing Camera CCA board (3) will be underneath lens and Pixelink 155mm Flex Cable will be stored within the case (no hole cut out as in Selfie Camera). Final products can be seen below:

Note: Secure all nuts with 3M Scotch-Weld epoxy adhesive EC-2216 B/A.

Gore Aerospace USB 3.0 Cable

Pinout:



Final Product:

Note: Secure all connections with 3M Scotch-Weld epoxy adhesive EC-2216 B/A.

Software

The CatCam Software is a C++ file named slowMotionVideo.cpp and needs to be used with the Pixelink software development kit (SDK) proprietary package. The user is able to specify exposure time, frame rate and capture duration. The CatCam software uses proprietary functions from the Pixelink SDK, so the SDK needs to be installed on the platform being used to command the cameras.

The CatCam Software captures video for a specified number of seconds. The user can also specify the exposure time and frame rate of the video. The gain has been set to correct color and lighting in a lab setting.

Usage (based on a Raspberry Pi): ./slowMotionVideo [-t capture_duration] [-b exposure_time] [-f playback_framerate] video_name

Where:
-t capture_duration How much time to spend capturing video (in seconds).
-b exposure_time Exposure time in seconds.
-f playback_framerate Framerate (f/s) that will be used for playback.
video_name Name of file to generate (it will be postfixed with .avi)

Example: ./SlowMotionVideo -t 30 clip
This will capture a video, called clip.avi, that records for 30 seconds.