Sampling Tube Test Report

Project: UAVPAYG19 **WP Name:** Subsystem Testing **WP Number:** WP-ST-06	**Type of Test:** Unit Test	
Test Article: Sampling Tube Operation	**Part Number:**	**Serial Number:**
System Requirements: [REQ-M-01] [REQ-M-08] [REQ-M-09] [REQ-M-14]	**Test Equipment:** See “equipment used” section of each test	
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Test Summary

This test report contains tests related to the development of the sampling tube subsystem. These tests ensure that the sampling tube subsystem meets the outlined requirements and that it is ready for integration once all the tests have been successfully completed. The successful tests completed include driving the motor with software, testing the force requirement to cut into expanded polystyrene, assembling the parts, testing the extension and retraction of the cutting tool, using the assembled system to sample the simulated soil, and to ensure it is within weight.

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Revision Record

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0.1	Draft Release	21/10/2022	J.N
1.0	Final Release	28/10/2022	J.N
1.1	Final Amendments	28/10/2022	J.N

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Definitions

ENC	Enclosure
TAIP	Target Acquisition & Image Processing
ST	Sampling Tube
ASP	Advance Sensor Payload
UAV	Unmanned Aerial Vehicle
AQS	Air Quality Sensor

1 Introduction

The team members of Group 19 have been appointed to research, design, plan and implement an Advance Sensor Payload (ASP) for Unmanned Aerial Vehicle (UAV) target detection and air quality monitoring in GPS denied environments. The group has committed to the specified budget whilst implementing the project requirements stated by the client. The team has also committed to meeting the deadline date specified by the client with a full functioning ASP that has been tested to ensure the client requirements have been met. This document is a report on the tests conducted of UAVPAYG19 for the subsystem of Sampling Tube (ST). This subsystem is required to extend, take a simulated soil sample, and then retract to its original position.

1.1 Scope

The scope of the project is to research, plan, design, implement and test the ASP for UAV target detection in GPS denied environments. This document contains the objectives of the test, the equipment used, in depth descriptions of the tests, results, an analysis of these results and a conclusion with recommendations. The purpose of this test document is to see if the test satisfies the state System Requirements/HLO's in RD-1

1.2 Background

The Queensland University of Technology's Airborne System Lab (ASL) has commissioned the group UAVPAYG19 to design and develop a payload capable in detecting specific objects, recording air quality data to be displayed on a web interface and to pierce a ground sample. This payload is to be attached to a S500 UAV which will complete an automated flight path. The payload is mounted on the bottom of the UAV using a provided bracket. This payload must contain all components to complete its required tasks. These components are:

- Raspberry Pi 3b+
- Raspberry Pi Camera
- Pimoroni Enviro+ sensor
- DF15RSMG 360 Degree Motor

The payload is required to identify three targets, a valve (In open or closed position), a fire extinguisher and an ArUCO marker. The Pimoroni sensor is to be used to record air temperature, pressure humidity, light and potentially hazardous gas level data. This data along with a live feed of the Raspberry Pi Camera is to be visualized on a Web Interface. Lastly a soil sample must be obtained using a sampling mechanism.

2 Reference Documents

2.1 QUT avionics Documents

RD/1	UA–System Requirements	UAVPayloadTAQ System Requirements
RD/2	UA –Customer Needs	Advanced Sensor Payload for UAV Target Detection and Air Quality Monitoring in GPS Denied Environments
RD/3	UAVPAYG19-PM-PMP-03	PMP Document
RD/33	UAVPAYG19-ST-FD-01	Final Design - Sampling Tube

2.2 Non-QUT Documents

Doc-1	DF15RSMG 360 Degree Motor	DFROBOT, "DF15RSMG 360 Degree Motor (20kg)", n.d. [Online]. Available: https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SER0035_Web.pdf. [Accessed 14/08/2022]

3 Test Objectives

The objective of the tests being carried out are to ensure the successful design and operation of the Sampling Tube subsystem. These tests will demonstrate that a Raspberry Pi is able to control the servo motor, that the 3D printed cutting tool can penetrate the simulated expanded polystyrene soil, and that the 3D printed design extends and retracts successfully. Once these tests have been completed, the subsystem will be ready to be integrated with the other subsystems.

Table 1: Sampling Tube Subsystem Requirements

Requirement	Description
REQ-M-01	The UAVPayloadTAQ shall remain under the maximum weight of 320 g and comply with an IP41 rating. The air quality sensors must be exposed to the environment to allow for accurate reading.
REQ-M-08	The payload shall include a sampling tube design to collect a simulated soil sample. The payload system must protrude or push into the simulated soil. A mark must be left on the simulated soil (10mm deep, 10mm diameter hole), to ensure the sampling tube has made contact with the soil.
REQ-M-09	The payload shall activate the sampling tube mechanism to collect a simulated soil sample only after the UAV has landed on a designated Aruco marker. Once the soil is sampled the sampling tube must retract to its original position.
REQ-M-14	Developed solution shall conform to the systems engineering approach.

4 Testing

The following tests have been split up and listed in the order in which they should be conducted. They have been designed to be progressive steps towards the final product of the ST subsystem. Upon successful completion, the next test can be carried out to ensure that all the design requirements are met. Although only one software test is being conducted, there will be a software component within each of the five mechanical tests. By conducting the software test to run the motor first, it allows for the mechanical tests to focus on the mechanical design of the ST subsystem.

4.1 Software Test

One software test is required for the sampling tube subsystem. This software test is to identify how the signals control the servo motor so that it can be correctly driven in the mechanical tests. The ST design is put at risk of breakage if driven in the wrong direction.

4.1.1 Software Test 1: Driving the Servo Motor from Software

Python code will be deployed and tested on a Raspberry Pi using the ports that have been identified to be used for the system interface integration. This test is to ensure that the servo motor can be controlled from software and to determine what direction the motor turns.

Equipment used:

The equipment used in this test consists of the following:

- Raspberry Pi with Power Adapter
- 5V Regulator Adaptor Testing Unit.
- DF15RSMG 360 Degree Motor
- Computer
- Wi-Fi Access Point

Procedure:

Following is the procedure used to conduct the test:

1. Connect power to Pi
2. Connect power to 5V Regulator Adaptor Testing Unit
3. Connect Servo Motor to 5V Regulator Adaptor Testing Unit
4. Connect 5V Regulator Adaptor Testing Unit to the Pi on GPIO #4 (Pin #7) and Ground to Ground
5. Connect Pi and Computer to Wi-Fi
6. Connect Computer to the Raspberry Pi via SSH
7. Run test code with value smaller than the nominal value, but within the range value, Record the direction of the Servo Motor output
8. Run test code with value greater than the nominal value, but within the range value, Record the direction of the Servo Motor output

Code:

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(4, GPIO.OUT, initial=False)
p = GPIO.PWM(4,50)

# speed% = (<time_ns>-1.5)*100
# speed setting: <time_ns>/((1/50)*1000*1000)*100
# min value: 2 = Reverse/Up (max speed) -> 6.5
# max value: 12 = Forward/Down (max speed) -> 7.5
NOMINAL=7 # the 'zero' PWM %age
RANGE=5   # maximum variation above/below NOMINAL

p.start(7)

print("start")
p.ChangeDutyCycle(5)
time.sleep(5)

print("done")
p.ChangeDutyCycle(NOMINAL)
time.sleep(0.1)
GPIO.cleanup()
```

Figure 1 – Code used to conduct test.

Results and Evidence:

The test results found that a value greater than the nominal around drive the motor in a clockwise direction, when looking from the base of the servo motor towards the motor output. A value below the nominal would drive the motor anti-clockwise. Video evidence can be seen in the following link https://youtu.be/tfMNlR1S8JI, showing that the test was successful, and this information can now be applied to finish the ST subsystem design.

4.2 Hardware Tests

The following four hardware tests are necessary to ensure the preliminary design and final design meet the requirements of the project within the provided restrictions and parts provided to us. These tests include a force test on the expanded polystyrene using the designed cutting tool, a fit test for the designed 3D printed parts, a complete assembly test to ensure that the motor can extend and retract the cutting tool, and a test to ensure that the complete subsystem can cut into expanded polystyrene. Lastly, a final weight test is conducted to ensure it is within budget.

4.2.1 Hardware Test 1: Cutting Tool Expanded Polystyrene Cut Test

A test print of the designed cutting tool will be used to cut into a sample of expanded polystyrene. Using this information helps to ensure that the preliminary design has been correctly drawn up and that the motor can provide sufficient torque to power the system.

Equipment Used:

The equipment used in this test consists of the following:

- 3D Printed Cutting Tool
- Sample Piece of Expanded Polystyrene
- Force-Plate Machine

Procedure:

1. Turn force plate machine on
2. Place expanded polystyrene on force plate machine
3. Hold the 3D printed cutting tool so that the teeth are touching the expanded polystyrene
4. Apply a light rotational and downward force
5. Increase force applied until cutting tool cuts through expanded polystyrene
6. Record the resultant force displayed by the force-plate machine

Results and Evidence:

With the assistance of Dr. Veronica Gray, a quick test was conducted to find the amount of force needed to cut into the expanded polystyrene. It was identified that roughly 5N of force was necessary over three tests. Unfortunately, no photos or videos were taken of the process, but a photo of the sample 3D printed cutting tool can be seen in Figure 2. The test was conducted by rotating the tool clockwise, so that the cutting teeth cut into the material rather than digging at it.

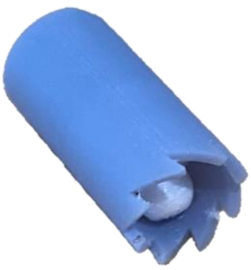


Figure 2 – Cutting tool used on force machine with expanded polystyrene still inside.

4.2.2 Hardware Test 2: Design Assembly Fit Test

A test print of the designed sampling tube including the drive shaft, casing, and cutting tool. This test will be used to check that all the prototype sample parts fit together before doing a complete print to save on resources and time.

Equipment Used:

The equipment used in this test consists of the following:

- 3D Printed Sampling Tube Drive Shaft
- 3D Printed Sampling Tube Casing
- 3D Printed Sampling Tube Cutting Tool

Procedure:

1. Clean 3D printed pieces to remove any plastic build-up
2. Place and rotate the cutting tool into the end of the casing
   Record any issues with the pieces fitting
3. Place the drive shaft into the casing so that it fits within the casing
   Record any issues with the pieces fitting
4. If all pieces fit:
   a. Take out the drive shaft and place into the end of the cutting tool
   b. Attempt to rotate the drive shaft while holding the enclosure to move the cutting tool up and down
   c. Record any difficulties

Results and Evidence:

Upon assembling the parts, it was evident that the 3D printed design was successful. All parts could be fitted together as per the method of this test report, and the cutting tool part is able to be rotated by the drive shaft. Figure 3 shows the individual sample parts that are a cut-down version of the full part to reduce wastage if the test was unsuccessful. Figure 4 shows the complete assembly of these parts and that they do all fit together. One change that could be made for the final print is to increase the size of the hexagonal drive shaft by 0.25mm. This will help reduce a small wobble caused by a gap between the drive shaft and the cutting tool.

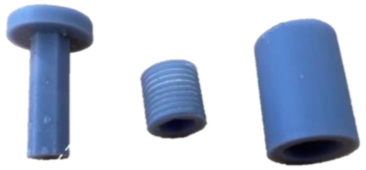


Figure 3 – Sample 3D printed parts.

Figure 4 – Sample 3D printed parts assembled.

4.2.3 Hardware Test 3: Design Assembly Test Run

The following hardware test will check the designed sampling tube's ability to extend and retract as per REQ-M-09. All parts of the sampling tube design will be assembled and controlled by the Raspberry Pi for this test.

Equipment Used:

The equipment used in this test consists of the following:

- 3D Printed Sampling Tube Drive Shaft
- 3D Printed Sampling Tube Casing
- 3D Printed Sampling Tube Cutting Tool
- Raspberry Pi with Power Adapter
- 5V Regulator Adaptor Testing Unit
- Nylon motor output mount
- 1x provided motor output screw
- 4x provided M2 screws
- 4x M2 bolts & nuts
- DF15RSMG 360 Degree Motor
- Computer
- Wi-Fi Access Point

Procedure:

1. Clean 3D printed pieces to remove any plastic build-up
2. Place and rotate the cutting tool into the end of the casing
   Record any issues with the pieces fitting
3. Place and screw the nylon motor output mount onto the servo motor
4. Screw the drive shaft into the nylon motor output mount
5. Place the casing onto the drive shaft so that it fits within the casing, rotating the cutting tool as needed to align the hexagonal drive shaft
   Record any issues with the pieces fitting
6. Using the M2 nuts & bolts, secure the sampling tube enclosure onto the servo motor
7. If all pieces fit:
   a. Connect power to Pi
   b. Connect power to 5V Regulator Adaptor Testing Unit
   c. Connect Servo Motor to 5V Regulator Adaptor Testing Unit
   d. Connect 5V Regulator Adaptor Testing Unit to the Pi on GPIO #4 (Pin #7) and Ground to Ground
   e. Connect Pi and Computer to Wi-Fi
   f. Connect Computer to the Raspberry Pi via SSH
   g. Run test code with value larger than the nominal value, but within the range value to extend the cutting tool approximately 12mm. Record any issues.
   h. Run test code with value smaller than the nominal value, but within the range value to retract the cutting tool approximately 12mm. Record any issues.

Code:

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(4, GPIO.OUT, initial=False)
p = GPIO.PWM(4,50)

# speed% = (<time_ns>-1.5)*100
# speed setting: <time_ns>/((1/50)*1000*1000)*100
# min value: 2 = Reverse/Up (max speed) -> 6.5
# max value: 12 = Forward/Down (max speed) -> 7.5
NOMINAL=7 # the 'zero' PWM %age
RANGE=5   # maximum variation above/below NOMINAL

p.start(7)

print("start")
p.ChangeDutyCycle(5)
time.sleep(5)

print("done")
p.ChangeDutyCycle(NOMINAL)
time.sleep(0.1)
GPIO.cleanup()
```

Figure 5 – Code V1 used to conduct test.

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(4, GPIO.OUT, initial=False)
p = GPIO.PWM(4,50)

# speed% = (<time_ns>-1.5)*100
# speed setting: <time_ns>/((1/50)*1000*1000)*100
# min value: 2 = Reverse/Up (max speed) -> 6.5
# max value: 12 = Forward/Down (max speed) -> 7.5
NOMINAL=7 # the 'zero' PWM %age
RANGE=5   # maximum variation above/below NOMINAL

p.start(7)

print("start")
#p.ChangeDutyCycle(5)
#time.sleep(5)
for x in range(18):
    p.ChangeDutyCycle(NOMINAL+5)
    time.sleep(1)
    p.ChangeDutyCycle(NOMINAL-1)
    time.sleep(0.25)
    p.ChangeDutyCycle(NOMINAL)
    time.sleep(0.25)

print("done")
p.ChangeDutyCycle(NOMINAL)
time.sleep(0.1)
GPIO.cleanup()
```

Figure 6 – Code V2 used to conduct test.

Results and Evidence:

The first test attempt had a successful fit for the assembly seen in Figure 7, however, encountered a critical issue while running the test code in Figure 5. The drive shaft shattered during its first extension run with the damage visible in Figure 8.

Figure 7 – Assembled sampling tube.

Figure 8 – Drive shaft breakage.

After the first test, the drive shaft was redesigned to fit on the nylon motor output mount better. Additional height was also incorporated into the sampling tube enclosure to prevent the screws from digging into the enclosure.

On the second test run, WD-40 was used to help lubricate the system. As it can be seen in this video https://youtu.be/XYoIwFSS9b4, a critical failure occurred. Figure 9 shows that the drive shaft shattered again, and the sampling tube enclosure exploded. It can also be seen that there is a significant scrape along the side of the sampling tube enclosure wall. Figure 10 shows with a baseplate print of the sampling tube enclosure that there is a significant offset from the centre of the drive shaft.

Figure 9 – Enclosure and drive shaft breakage.

Figure 10 – Plate to show offset.

To resolve these issues, the offset around the drive shaft hole was corrected by 1mm, and the diameter of the hole around the drive shaft was widened by 3mm. An additional software measure was implemented to help reduce tension, seen in Figure 6. This works by running the motor in the desired direction at full speed for 1 second, rotating back at slowest speed for 0.25 seconds, and then pausing for 0.25 seconds before looping over. This generates a pulse effect and allows for the drive shaft to slide with the change of height of the cutting tool.

Extending: https://youtu.be/xwcjZVV0yHs,
Retracting: https://youtu.be/AZXkdM1-_50.

To meet the final requirement for the test, the cutting tool must extend and retract approximately 12mm. The following two images were sourced from the two videos for the third test of this section containing the extension and retraction of the mechanism. Figure 11 shows it starting at 4.8mm, Figure 12 showing it extended at 6mm, and Figure 13 showing it finishing at 4.7mm.

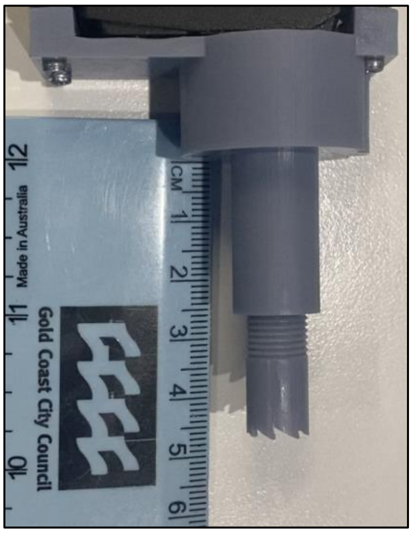


Figure 11 – ST Starting position.

Figure 12 – ST Extension.

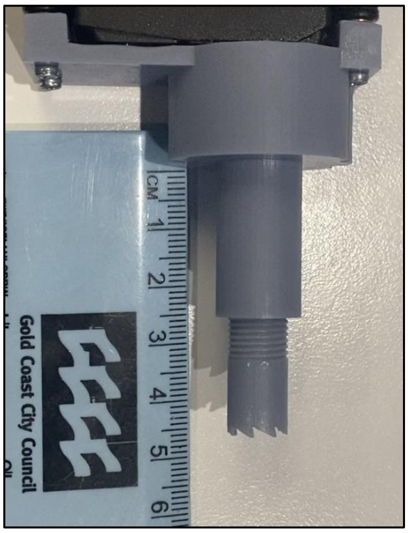


Figure 13 – ST Retraction.

4.2.4 Hardware Test 4: Full Design Cut Test

The following test is the final mechanical test that should be completed before integrating the sampling tube subsystem with the other subsystems. It will ensure that the sampling tube is able to meet REQ-M-08 by testing that it is capable of cutting into expanded polystyrene.

Equipment Used:

The equipment used in this test consists of the following:

- 3D Printed Sampling Tube Drive Shaft
- 3D Printed Sampling Tube Casing
- 3D Printed Sampling Tube Cutting Tool
- Raspberry Pi with Power Adapter
- 5V Regulator Adaptor Testing Unit
- Nylon motor output mount
- 1x provided motor output screw
- 4x provided M2 screws
- 4x M2 bolts & nuts
- DF15RSMG 360 Degree Motor
- Computer
- Wi-Fi Access Point
- Expanded Polystyrene piece

Procedure:

1. Clean 3D printed pieces to remove any plastic build-up
2. Place and rotate the cutting tool into the end of the casing
   Record any issues with the pieces fitting
3. Place and screw the nylon motor output mount onto the servo motor
4. Screw the drive shaft into the nylon motor output mount
5. Place the casing onto the drive shaft so that it fits within the casing, rotating the cutting tool as needed to align the hexagonal drive shaft
   Record any issues with the pieces fitting
6. Using the M2 nuts & bolts, secure the sampling tube enclosure onto the servo motor
7. Connect power to Pi
8. Connect power to 5V Regulator Adaptor Testing Unit
9. Connect Servo Motor to 5V Regulator Adaptor Testing Unit
10. Connect 5V Regulator Adaptor Testing Unit to the Pi on GPIO #4 (Pin #7) and Ground to Ground
11. Connect Pi and Computer to Wi-Fi
12. Connect Computer to the Raspberry Pi via SSH
13. Place and hold piece of expanded polystyrene 1-2mm away from the cutting tool and ensuring the motor is also secured in position
14. Run the test code to extend and retract the sampling tube, recording any issues.

Code:

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BCM)
GPIO.setup(4, GPIO.OUT, initial=False)
p = GPIO.PWM(4,50)

# speed% = (<time_ns>-1.5)*100
# speed setting: <time_ns>/((1/50)*1000*1000)*100
# min value: 2 = Reverse/Up (max speed) -> 6.5
# max value: 12 = Forward/Down (max speed) -> 7.5
NOMINAL=7 # the 'zero' PWM %age
RANGE=5   # maximum variation above/below NOMINAL

p.start(7)

print("start")
#p.ChangeDutyCycle(5)
#time.sleep(5)
for x in range(18):
    p.ChangeDutyCycle(NOMINAL+5)
    time.sleep(1)
    p.ChangeDutyCycle(NOMINAL-1)
    time.sleep(0.25)
    p.ChangeDutyCycle(NOMINAL)
    time.sleep(0.25)

print("done")
p.ChangeDutyCycle(NOMINAL)
time.sleep(0.1)
GPIO.cleanup()
```

Figure 14 – Code V2 used to conduct test.

Results and Evidence:

The final subsystem test for the ST subsystem has been deemed a success. The expanded polystyrene was successfully cut, with the cutting tool also retracting to its original position. A full video can be seen at https://youtu.be/DTUREn0UTus, with Figure 15 showing the width and Figure 16 showing the depth hole cut into the expanded polystyrene. The hole created meets the 10mm wide by 10mm deep hole requirement as the expanded polystyrene tends to grab as the balls can be up to 3mm wide, making the simulated soil not an ideal medium to test in.

Figure 15 – Width of cut hole.

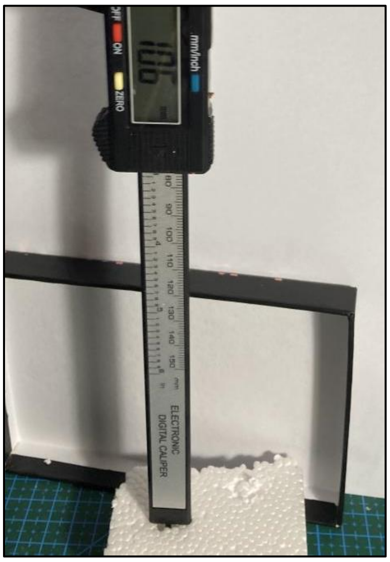


Figure 16 – Depth of cut hole.

4.2.5 Hardware Test 5: Weight Test

The last test to be carried out is to ensure that the total weight of the ST Subsystem is within the expected limits outlined in the PMP document RD/3. It will ensure that the sampling tube is able to meet REQ-M-01 by testing that the subsystem is within the allocated weight allowance.

Equipment Used:

The equipment used in this test consists of the following:

- 3D Printed Sampling Tube Drive Shaft
- 3D Printed Sampling Tube Casing
- 3D Printed Sampling Tube Cutting Tool
- 5V Regulator Adaptor Testing Unit
- Nylon motor output mount
- 1x provided motor output screw
- 4x provided M2 screws
- 4x M2 bolts & nuts
- DF15RSMG 360 Degree Motor
- Scales

Procedure:

1. Turn scales on
2. Tare the scales
3. Place all the listed equipment onto the scales
4. Record weight

Results and Evidence:

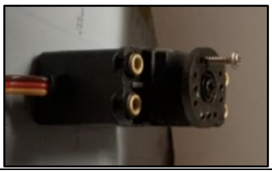
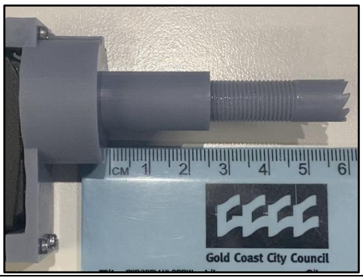
As it can be seen in Figure 17, the resultant weight of the ST Subsystem is roughly 79g. Knowing that the servo motor weights 60g from DOC-1, the ST 3D printed design weighs 19g. This shows that the test has been successful as the ST Subsystem fits within the estimated 20g budget.

Figure 17 – ST subsystem on scales.

5 Results

Table 2 shows the results of all the tests that were completed. All tests successfully completed.

Table 2: Results from tests

Test Title	Result	IMG	Requirement Met
Driving the Servo Motor from Software	Success		REQ-M-09, REQ-M-14
Cutting Tool Expanded Polystyrene Cut Test	Success		REQ-M-09, REQ-M-14
Design Assembly Fit Test	Success		REQ-M-09, REQ-M-14
Design Assembly Test Run #1	Fail		REQ-M-09, REQ-M-14
Design Assembly Test Run #2	Fail		REQ-M-09, REQ-M-14
Design Assembly Test Run #3	Success		REQ-M-09, REQ-M-14
Full Design Cut Test	Success		REQ-M-08, REQ-M-09, REQ-M-14

Weight Test	Success		REQ-M-01

6 Analysis

The analysis section will discuss if the aims of the test have been achieved and were there any issues involved with this.

6.1 Software Analysis

6.1.1 Software Test 1: Driving the Servo Motor from Software

The server motor software control test was successful. The direction in which the motor turns was determined and recorded so that future tests could be conducted with knowledge of how to control the motor.

6.2 Hardware Analysis

6.2.1 Hardware Test 1: Cutting Tool Expanded Polystyrene Cut Test

The cutting tool force test was a success as a plausible force result was collected. In the final report RD/33, it was identified that with a 5N force to drive the cutting tool there would be plenty of headroom to sufficiently overcome friction from abnormalities in the plastic printing process.

6.2.2 Hardware Test 2: Design Assembly Fit Test

The design assembly fit test using 3D printed sample parts was successful. All parts sufficiently fitted together, however, the hexagonal drive shaft was identified as being slightly too small. A recommendation to increase the size by 0.25mm brining it from 0.5mm expansion allowance to 0.25mm allowance. This will help maintain contact and prevent damage to the shaft the final design.

6.2.3 Hardware Test 3: Design Assembly Test Run

In order to successfully complete this test, three tests were needed to be conducted due to critical failures in the first two test. The first test saw the drive shaft break from a high torsion force as the screws attaching it to the nylon motor output mount were scraping against the ST enclosure. To help correct this, the drive shaft was altered to maintain a better connection with the nylon motor mount, and more clearance was provided for the screws in the ST enclosure. The second test saw failures due to the ST enclosure have an incorrect offset by 1mm, causing the drive shaft to rub against it and snap both the ST enclosure and drive shaft even with the use of WD-40. The final test was considered a success. With the offset having been corrected, using WD-40, and making a software alteration to relieve stress in the drive shaft, the motor could extend and retract the cutting tool to the specified length of approximately 12mm.

6.2.4 Hardware Test 4: Full Design Cut Test

The full design cut test aimed to show that the designed sampling tube could cut into the simulated soil. Despite the testing conditions being suboptimal, it was able to cut through and take a sufficiently sized sample 11.5mm wide and 10.6mm deep. Although this sample is slightly oversized, the cause is due to expanded polystyrene being up to 3mm wide, so that cutting tool can take chunks out of the wall.

6.2.5 Hardware Test 5: Weight Test

The weight test that was undertaken was successful and the combined weight of 79g was underneath the combined total off 60g for the motor and 20g for the 3D printed sampling tube.

7 Conclusions and Recommendations

The test report has proven that the design of the sampling tube subsystem meets all requirements and that it is ready to be integrated with the other subsystems. The motor is able to extend and retract, make a 10mm wide by 10mm deep hole, and fits within the total available weight budget. The successful outcome of all the tests are shown by meeting the applicable requirements in Table 3.

Table 3: Requirements Met

Requirement Code	Description	Requirement Met
REQ-M-01	The UAVPayloadTAQ shall remain under the maximum weight of 320 g and comply with an IP41 rating. The air quality sensors must be exposed to the environment to allow for accurate reading.	**Partially Met** – The ST Subsystem is within the specified limits. If all other subsystems are within weight, then this is successful.
REQ-M-08	The payload shall include a sampling tube design to collect a simulated soil sample. The payload system must protrude or push into the simulated soil. A mark must be left on the simulated soil (10mm deep, 10mm diameter hole), to ensure the sampling tube has made contact with the soil.	**Met** – The ST Subsystem is successful at protruding and taking a 10mm deep by 10mm diameter hole from the simulated soil.
REQ-M-09	The payload shall activate the sampling tube mechanism to collect a simulated soil sample only after the UAV has landed on a designated Aruco marker. Once the soil is sampled the sampling tube must retract to its original position.	**Partially Met** – Tube can extend and retract to original position. The UAV condition will be tested in an integration test to be successful.
REQ-M-14	Developed solution shall conform to the systems engineering approach.	**Successful**

Recommendations for future work would be to possibly change the hexagonal drive shaft to a triangular or square drive shaft to reduce the surface area that can cause friction within the turning piece. Also, a better 3D resin printer could be used as the drive shaft always came out with a little bend, increasing friction and stress within the sampling tube.