SPACE SYSTEMS DESIGN STUDIO | CORNELL UNIVERSITY

SPACECRAFT FLIGHT SIMULATOR

Operating Manual

OPERATING MANUAL

Spacecraft Flight Simulator

Revision A
May 7, 2019

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CHAPTER 1

SAFETY

1.1 Air Compressor Precautions

1. The air compressor's temperature sensor should never exceed 45^oC. If this happens, immediately release air by loosening the valves. Once the compressor's pressure gauge reads 0psi, turn off the compressor. Leave the water pump on to cool the system and replace warm water with cold water if needed.
2. Make sure the lubricant (ISO VG46 or AW46) is filled above the red dot before compressor use. If not, use funnel to refill. The lubricant should be slightly above the red dot, not filled to the top.
3. The pressure setting should **always** be below 4500psi. The recommended pressure setting to use is 3000psi, but the compressor is rated for 4500psi.
4. There is potential danger of pipe burst or connecting fitting blow off under high pressure, please avoid body too near compressor when running.
5. Never leave the compressor unattended. Watch the pressure gauge until rated pressure is reached and manually stop by releasing the valves then turn off the compressor **after the system reaches 0psi.**

1.2 Electrical Precautions

Exercise abundant caution whenever accessing or interacting with any electronic component. Before interacting with the on-board electronics, it is essential to use an ESD anti-static wrist strap to prevent any unwanted damage to sensitive components. Also be aware that the testbed chassis is highly conductive; do not let any uninsulated wiring come into contact with the chassis to prevent shorts.

1.3 Air Bearing Handling

1. Do not move or apply loads unless air is flowing.
2. The air bearing operating pressure must be between 30psi-90psi. The 160kg maximum load rating of the air bearing is based on an operating pressure of 80psi. If the test bed is approaching 160kg, do not use the air bearing if the exit pressure of the air filter regulator is below 80psi.
3. Do not touch inner surfaces of the air bearing with fingers. Use clean gloves only.
4. Use high pressure air to clean the air bearing if needed.

1.4 Suspension Travel Range

The suspension system is driven along a vertical lead screw with a bronze flange nut clamped between two large aluminum plates. The system has two physical limitations on its travel range, which the user must note while raising or lowering the testbed. When lowering the suspension, stop the motor before the bronze flange bottoms out on the screw collar. This is very important as the friction between the collar and the hex nut allow the shaft pulley (unthreaded) to rotate the lead screw. When raising the testbed at the end of operation, the 3D printed brackets atop the large aluminum plates will impact the simple support plate at the top of the lead screw. Stop the suspension just before this point, then remember to cover the bearing to prevent impurities from damaging the surface.

1.5 Testbed Rotation Range

During operation, the testbed can freely rotate in 360 degrees about the z-axis (vertical). However due to the limitations of the system, it has only a rotation of +/- 45 degrees in the y-axis and x-axis. A white circular bumper is inside the testbed to prevent the system from impacting the support base, but other measures should be taken to avoid injury or malfunction. During operation, please ensure the suspension has been lowered as much as possible to avoid interference with the testbed rotation. When standing near the testbed, please maintain a safe distance so that the user is not harmed and the testbed operation is not disturbed.

CHAPTER 2

PRELIMINARY SETUP

2.1 Fill Propulsion Tanks

It is recommended to fill the propulsion tanks during non-work hours due to the noise. There are two options: 1) Use the cart to fill the tanks while they are attached to the test bed and 2) Fill spare tanks and switch the empty tanks on the test bed with new filled tanks. It is recommended to fill the tanks while they are on the test bed to avoid loosening the clamps and possible leakage from repeated unscrewing and screwing of the tanks.

For either option, the following procedure should be used to fill the air tanks:

1. Fill up the container with no less than 20L (5 gallons) of relatively cold water and place the water pump into the container.
2. If the lubricant is below the red dot, fill the compressor with ISO VG46 or AW46. It should be level with to slightly above the red dot. Make sure to fasten the breather again afterwards.
3. Attach the tank to the hose.
4. Make sure the knob above each air tank, on the brass manifold, is turned all the way either clockwise or anti-clockwise. This ensures that you are solely filling up each tank, not the whole system.
5. Open both drain and bleed valve.
6. Turn on the compressor and let it run for at least 30 seconds before filling.

7. Close the valves. This will start the filling.
8. Wait until the pressure gauge reaches the desired pressure, then open bleed valve. Turn off the compressor once the compressors pressure gauge reaches 0. **Do not turn off the compressor at desired pressure, use the bleed valve then shut down.** This avoids damaging the air compressor.
9. Detach the hose.

2.2 Supply Power to the Testbed

Ensure power is supplied to both the reaction wheel and thruster control circuits by connecting the detachable battery terminal (Figure 2.2) for each circuit. This should be done for **both** pairs of batteries.

Provide power to the testbed Raspberry Pi flight computer by plugging in the USB charging cable into the power pack. A red light near by the charging port should turn on to indicate that the computer is being powered. A green light will begin to flash indicating the Raspbian kernel boot. Finally, the USB hub will light up blue and power will be delivered to the Arduino microcontrollers powering the thrusters and reaction wheels.

2.3 Air Bearing Setup

Open Upson 458's air supply by turning the handle from its horizontal position to its vertical position (in line with the pipe). This should send air to the air bearing. Verify that the exit pressure of the air filter regulator, **not the room's**

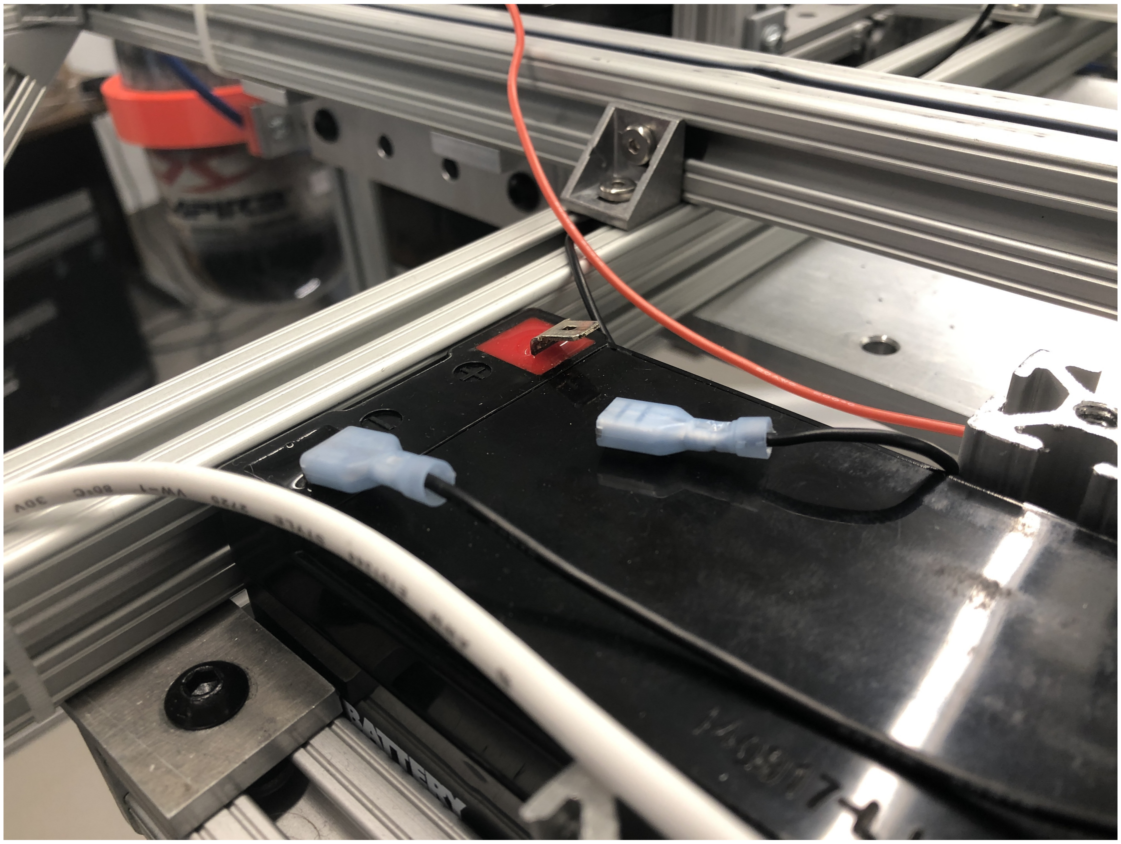

Figure 2.1: Detachable battery terminal

pressure supply, is between 30psi and 90psi. The ideal output pressure is 80psi, since this is what the air bearing load is based on.

WARNING: If the test bed total mass is approaching 160kg, do not use the air bearing if output pressure is below 80psi.

2.4 Open Cold Gas Propulsion System

When ready to start a test, open the valve of each tank to release air into the system. It is possible to open all five tanks or only one tank, depending on how much air is needed for the simulation. A red LED warning low-pressure indicator is located by the valve control circuit (Figure 2.4). The indicator turns on when power has been supplied and the PSI in the pressure manifold is below 140 PSI.

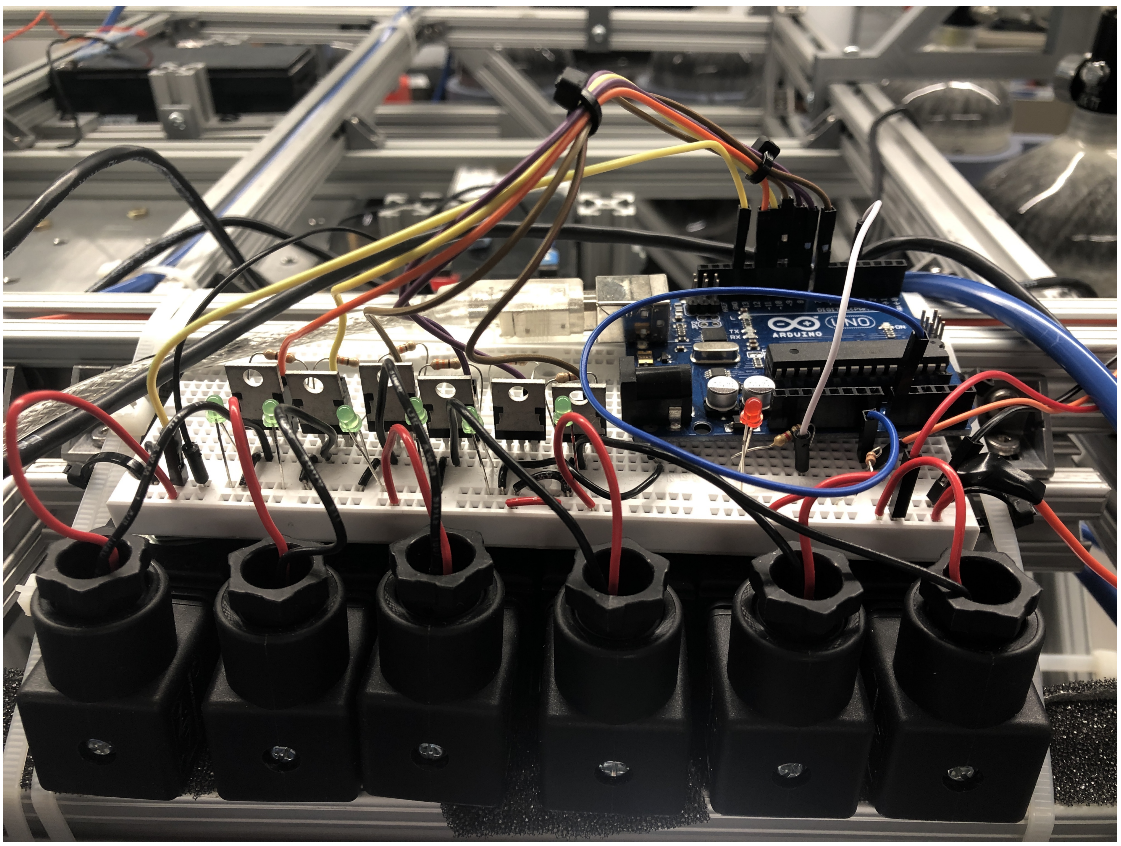

Figure 2.2: Low pressure indicator LED

2.5 Lowering Testbed

Only lower the test bed onto the air bearing **if air bearing is supplied with pressure,** after the Upson 458 air supply is opened. The motor controller (Figure 2.5) may be used to lower the testbed onto the air bearing.

1. Ensure controller dial is set to 0 initially, and the run/brake switch is set to "Brake".
2. Flip power switch to "On". A green light should indicate the system is ready.
3. Switch direction to "Reverse". This indicates the suspension will travel down the lead screw.
4. Flip the run/brake switch to "Run".
5. Turn dial to increase speed of travel. IMPORTANT, do not lower testbed into bearing at full speed. Make sure the hemispherical bearing is (roughly) centered while lowering into the pocket. There will be a very small (micron-level) gap between the two surfaces. As long as the air supply is constantly running and at 80 psi, the bearing should be safe.
6. Once the testbed is in position, lower the suspension to its resting position at the bottom of the base structure.
7. At the resting position, bring dial to 0 speed, switch run/brake to "Brake", direction to "Forward", and power to "Off".

Figure 2.3: Leeson Speedmaster Motor Controller

CHAPTER 3

OPERATING PROCEDURES

3.1 Simulink User Interface

Run the Simulink program named `FlightSimulator.slx` contained in the `Desktop/ssds-attest` directory. The following program should load onto the monitor. A listing of selected elements from the user interface is provided below.

`REBOOT` Executes the bash command "`sudo reboot now`" on the Raspberry Pi testbed flight computer. This command should be run when the testbed is not responding correctly to Simulink commands.

`SHUTDOWN` Executes the bash command "`sudo shutdown now`" on the Raspberry Pi testbed flight computer. This command should be run when the testbed is being shut down at the end of a session.

`STOP` Stops the Simulink simulation; equivalent to `Simulation > Stop` or the keyboard shortcut `Ctrl+Shift+T`.

`SEND COMMAND` Executes the current reaction wheel and thruster configuration on the testbed. Users should keep this button depressed until the desired commands have been executed on the testbed. This function should ideally be used sparingly, leaving ample time between each button press for the system to recognize and execute each command; repeatedly clicking this button may lead to system inoperation.

`X-WHEEL, Y-WHEEL, Z-WHEEL` These editable fields accept integers from 0 to 255, inclusive. Letting the axis of rotation be defined for each motor as the vector coming out of the spindle, entering `0` in the input field drives the reaction wheel at full speed counter-clockwise. Entering `128` stops the reaction wheel. Entering `255` drives the reaction wheel at full speed clockwise. The gauges display reaction wheel RPM as a percent of its rated maximum (3600 RPM). These values map linearly to the full dynamic RPM range of each wheel.

`VALVES 1–6` Toggling any combination of these switches to their on positions (right) will cause the corresponding thrusters to fire for 100 ms upon command send.

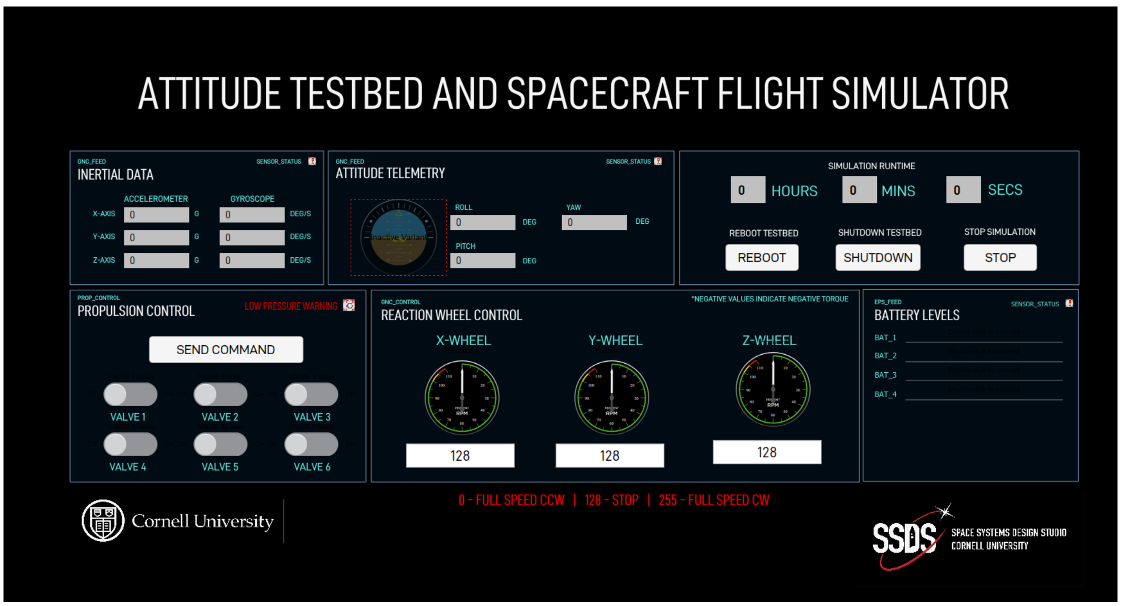

Figure 3.1: Spacecraft Flight Simulator user interface

The configuration is sent to the testbed only when the `SEND COMMAND` toggle is flipped on. Real-time telemetry may be viewed by opening the scope in the Simulink block diagram (Figure 3.2).

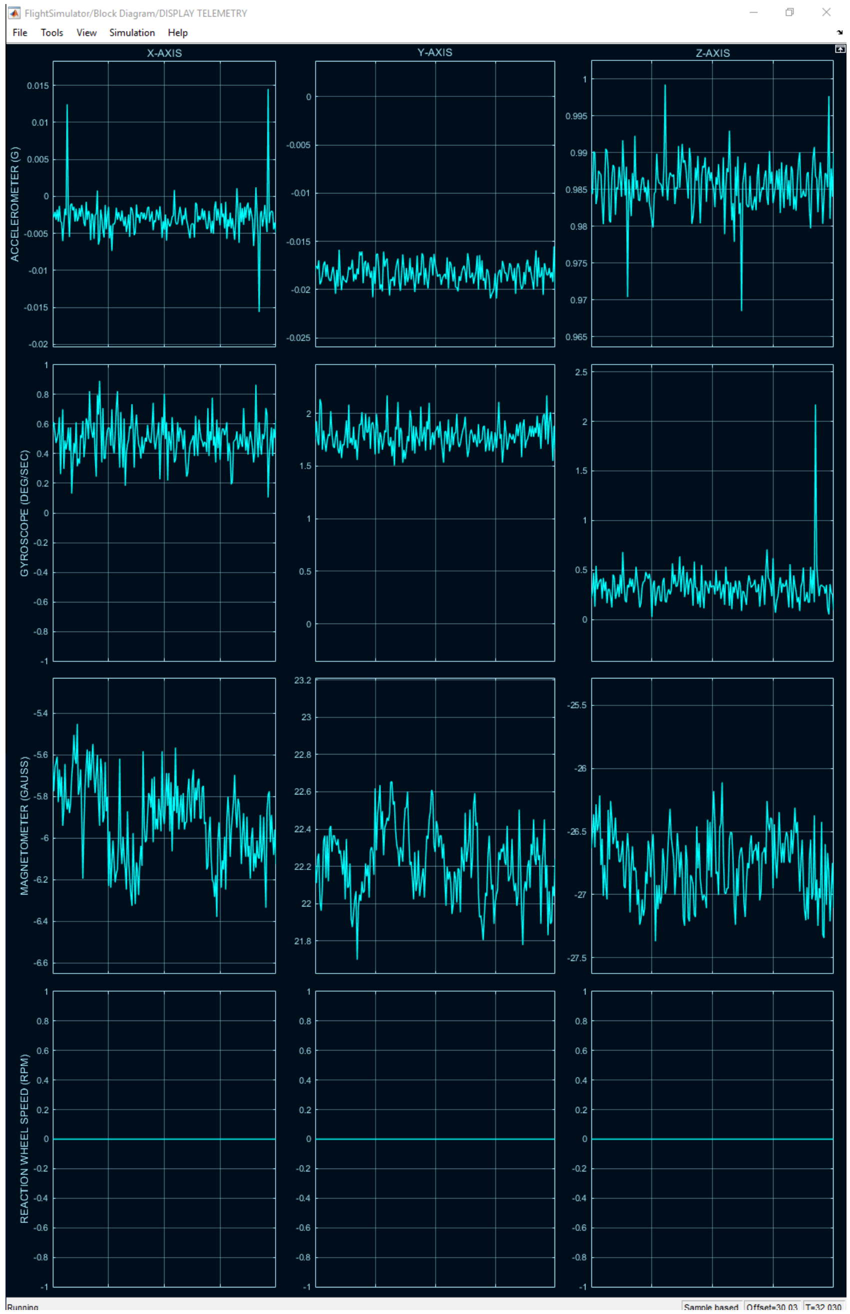

Figure 3.2: Real-time telemetry visualized on the scope

3.2 Using a Custom Control Algorithm

The Simulink control program may be simplified to a single subsystem that effectively acts as a plant in a closed-loop control system (Figure 3.3). A controller block may interface with the plant to achieve closed-loop and hardware-in-the-loop control. The controller block should consist of nine outputs: six valve state instructions (0 or 1) and three reaction wheel speed instructions (0-255). The block outputs accelerometer, gyroscope, magnetometer, and reaction wheel speed data in all three axes.

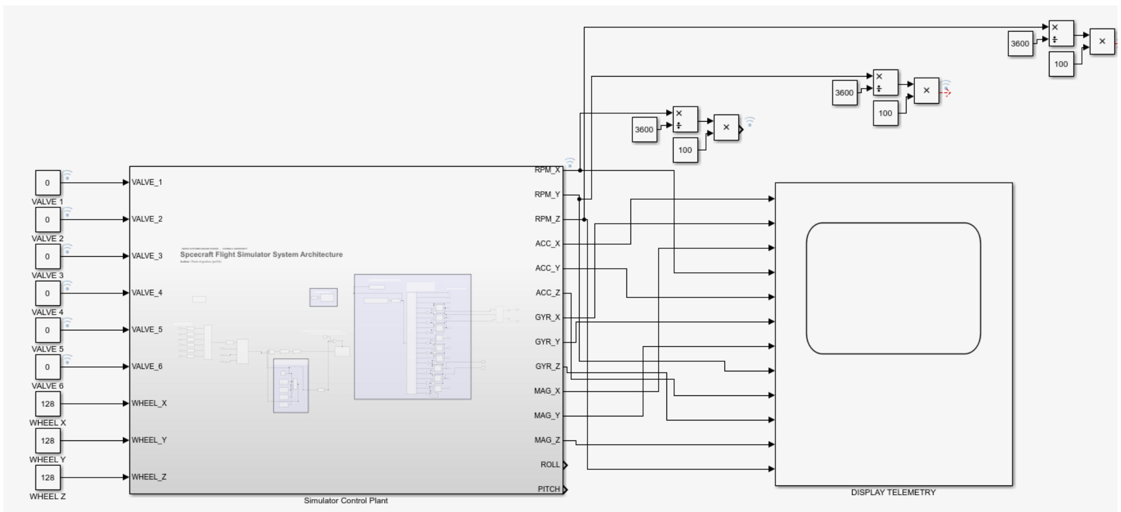

Figure 3.3: The Simulink program as a control plant

CHAPTER 4

ENDING A SIMULATION

4.1 Raise the Testbed

The air bearing should still be supplied with pressure, from the Upson 458 air supply.

1. Ensure controller dial is set to 0 initially, and the run/brake switch is set to ”Brake”.
2. Flip power switch to ”On”. A green light should indicate the system is ready.
3. Check direction is set to ”Forward”. This indicates the suspension will travel up the lead screw.
4. Flip the run/brake switch to ”Run”.
5. Turn dial to increase speed of travel. Make sure the air bearing is still being supplied with air until the testbed has been fully taken out of the pocket.

   NOTE: Make sure testbed frame is at a 45 degree offset with respect to the suspension frame so the testbed can be securely lifted.
6. Once the suspension has reached its upper travel limit, turn the dial to 0 speed.
7. At the top resting position, switch run/brake to ”Brake”, direction to ”Reverse”, and power to ”Off”.
8. Remember to cover the bearing surfaces to avoid damage.

4.2 Stop the Simulation and Retrieve Data

Stopping the Simulink simulation automatically saves all collected data since simulation start to the MATLAB workspace as a dataset titled "ScopeData." There are 12 signals contained within this object, each corresponding to a graph on the Simulink scope. The indices (1-12) and corresponding signals are:

1. x-axis accelerometer data
2. x-axis gyroscope data
3. x-axis magnetometer data
4. x-axis reaction wheel speed
5. y-axis accelerometer data
6. y-axis gyroscope data
7. y-axis magnetometer data
8. y-axis reaction wheel speed
9. z-axis accelerometer data
10. z-axis gyroscope data
11. z-axis magnetometer data
12. z-axis reaction wheel speed

4.3 Close the Propulsion System

At the end of operation, close the knob above each of the five air tanks. It does not matter whether the knob is turned all the way clockwise or anti-clockwise.

APPENDIX A
TROUBLESHOOTING

A.1 Testbed Issues

The testbed is not responding to user input.

Restart the Simulink program. There may be a traffic jam of serial commands in the queue to be sent to the testbed. If the problem persists after restarting the simulation multiple times, a hard reboot must be performed on the testbed. Carefully approach the testbed and touch the chassis to discharge any excess static electricity. Wearing an ESD anti-static wrist strap is also highly recommended. Unplug and replug the USB cable powering the Raspberry Pi Flight Computer. A Linux kernel reboot should clear out the serial queue and render the testbed responsive.

Alternatively, the power pack may have run out of charge. If this is the case, the Simulink scopes will "flatline." Recharge the power pack and follow the appropriate procedures to supply power to the testbed and begin the Simulink program.

The testbed is responding unexpectedly to user input.

If the testbed is firing thrusters or activating reaction wheels without user input, it is best to wait until the testbed stops. It may be acting on old commands in the serial instruction queue. Clear this queue by waiting until the testbed is no longer active, then follow the troubleshooting steps in the previous section.

A.2 User Interface Issues

Simulink crashes often.

Restart the computer. If the problem still persists, the Simulink program may be outdated. Ensure that the `.slx` file is up-to-date by opening Git Bash and issuing the following commands:

```
$ cd Desktop/ssds-attest
$ git pull
```

Simulink error: Multiple read COM port

There are multiple programs that are trying to access the XBee dongle COM port. Use the Windows Task Manager to close all other programs. Restart the simulation.

Simulink error: Cannot connect to COM port

There is an issue with the XBee dongle. Make sure that it is plugged in correctly. If the problem persists, quit the Simulink program and open XCTU or PuTTY to ensure that the XBee is receiving serial data in the form of a delimited numeric command string (Figure A.1). If PuTTY is used, set the COM port to '5' and baud rate to 9600 bps.

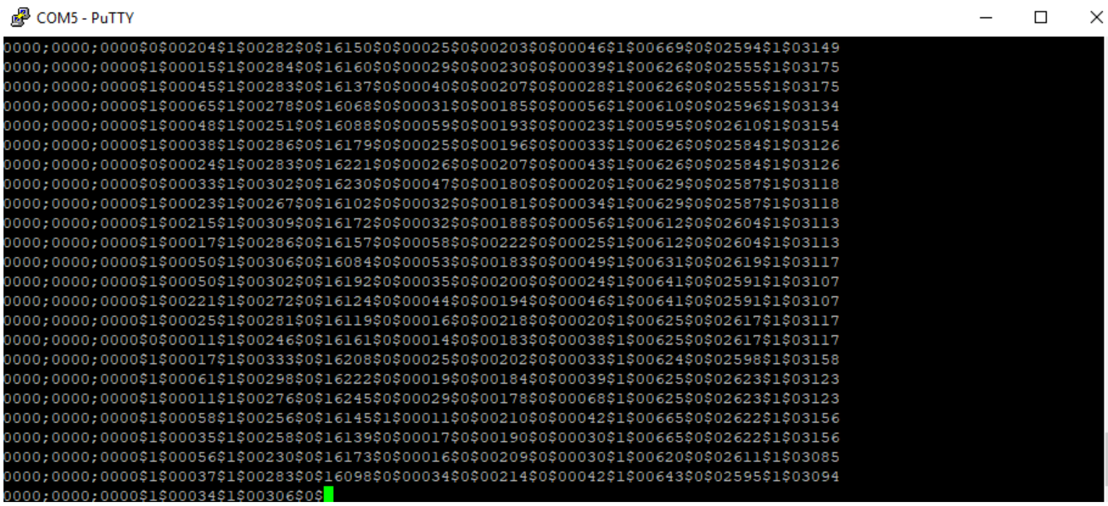

Figure A.1: PuTTY terminal showing correct telemetry data

A.3 Motor Controller Issues

The green light is not turning on when the power switch is toggled.

The wall plug cable is no longer connected properly. **Unplug the cable**, open the controller housing, and ensure that the "hot" (black) wire is securely connected to the L1 terminal, the neutral (white) wire to the L2 terminal, and the ground (green) wire to the ground terminal on the controller chassis. If the problem persists, the in-line fuse on the hot wire may have blown. Disconnect the wall power, and carefully remove and replace the blown fuse. The fuse should be voltage-rated to at least 230 VAC, and be rated to 3 A. Use Figure A.2 as a reference.

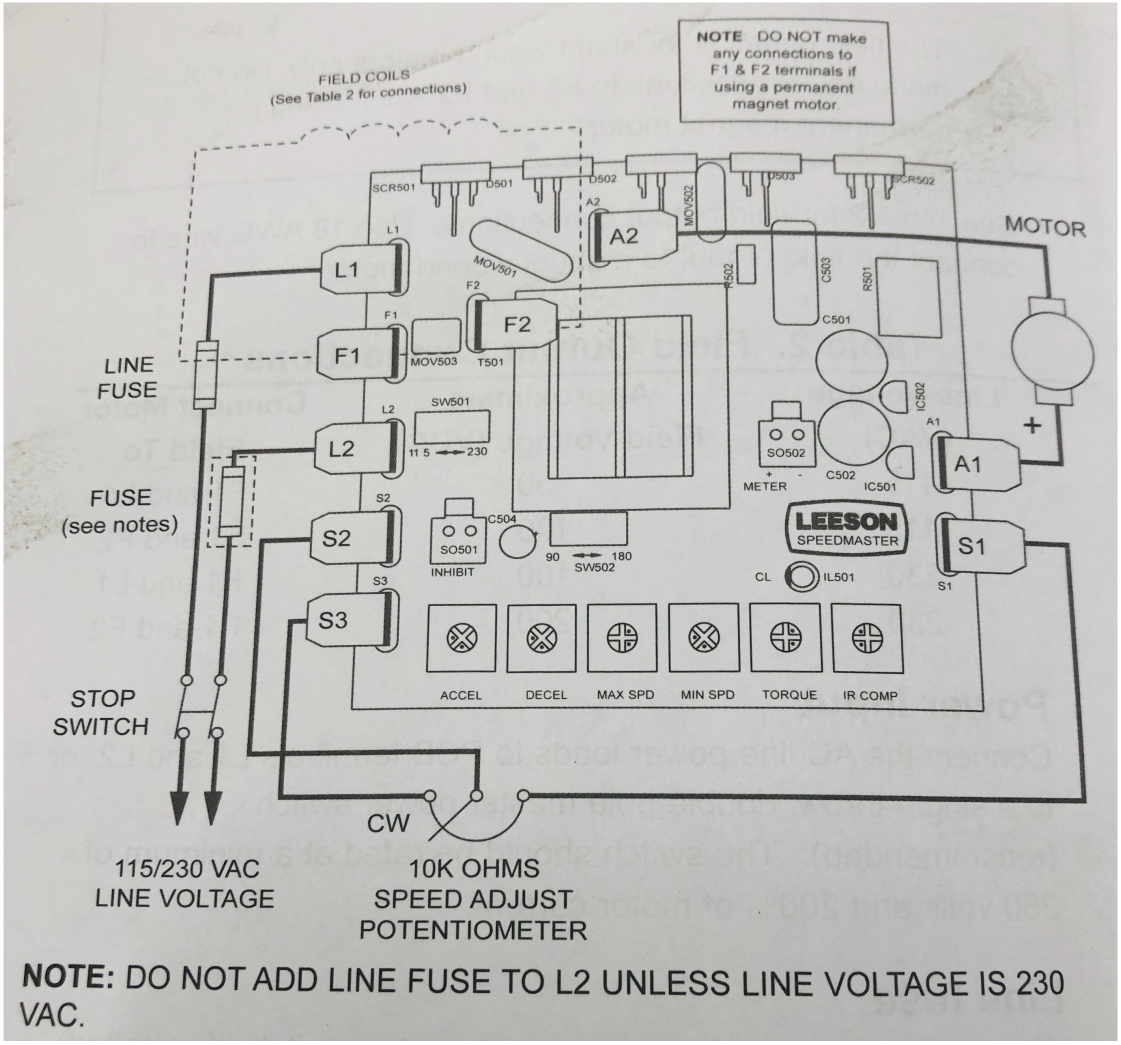

Figure A.2: Chassis Drive Connections

The controller is operable (i.e., the green light turns on), but the motor does not move.

The DC motor is no longer connected properly. **Unplug the wall power**, open the controller housing, and ensure that that the positive (red) wire is connected to A1, the negative (black) wire is connected to A2, and the ground (green) wire is connected to the chassis ground terminal. Use Figure A.2 as a reference.