USER MANUAL

3 DOF Helicopter Experiment

Set Up and Configuration

CAPTIVATE. MOTIVATE. GRADUATE.

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- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

CONTENTS

1 INTRODUCTION

The 3 DOF Helicopter plant is depicted in Figure 1.1. Two DC motors are mounted at each end of a rectangular frame and drive two propellers. The motors' axes are parallel and the thrust vector is normal to the frame. The helicopter frame is suspended from an instrumented joint mounted at the end of a long arm and is free to pitch about its centre. The arm is installed on an additional 2-DOF instrumented joint which allows the helicopter body to move in the elevation and yaw directions. The other end of the arm carries a counterweight such that the effective mass of the helicopter is light enough for it to be lifted using the thrust from the motors.

A positive voltage applied to the front motor causes a positive pitch while a positive voltage applied to the back motor causes a negative pitch. A positive voltage to either motor also causes an elevation of the body. If the body pitches, the thrust vectors result in a travel of the body (i.e., yaw of the arm) as well. The vertical base is equipped with an eight-contact slip ring. Electrical signals to and from the arm and helicopter are channelled through the slip ring to eliminate tangled wires, reduce friction, and allow for unlimited and unhindered travel.

Figure 1.1: 3 DOF Helicopter when running.

As shown in Figure 1.2, the 3 DOF Helicopter can also be fitted with an Active Mass Disturbance System (ADS). The ADS is comprised of a lead-screw, a DC motor, an encoder, and a moving mass. The lead-screw is wound through the mass such that when lead is rotated the mass moves along the helicopter arm linearly. One end of the lead-screw is connected to a DC motor and the other end has an encoder. As the motor is driven, the lead-screw rotates and causes the mass to move. Using the encoder measurement and a position controller, the user can move the mass to a desired position and actively disturb the helicopter.

Caution: This equipment is designed to be used for educational and research purposes and is not intended for use by the general public. The user is responsible to ensure that the equipment will be used by technically qualified personnel only.

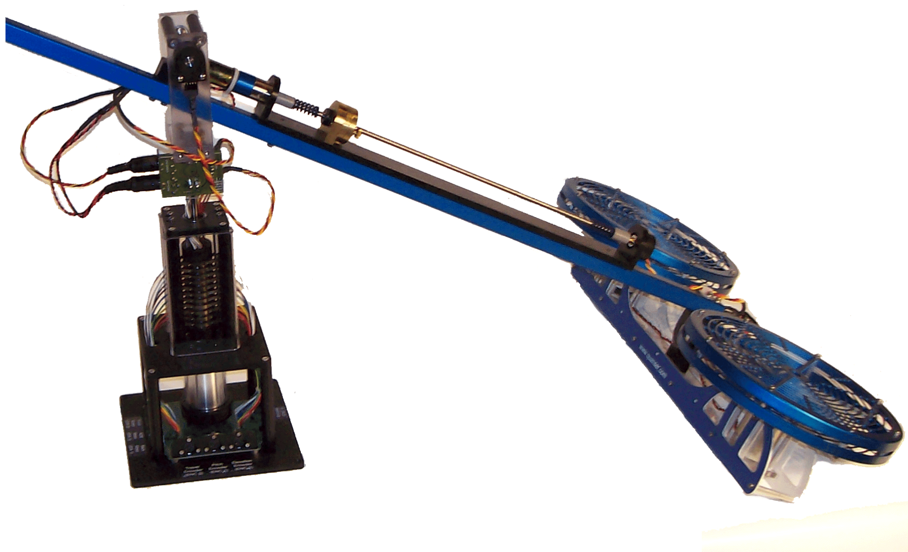


Figure 1.2: Active Disturbance System on the 3 DOF Helicopter .

2 SYSTEM DESCRIPTION

2.1 Components

Section 2.1.1 lists the components on the 3 DOF Helicopter plant and Section 2.1.5 describes the components on the 3 DOF Helicopter device with the Active Disturbance System (ADS).

2.1.1 3 DOF Helicopter Components

The components comprising the 3 DOF Helicopter system are labeled in figures 2.1, 2.2, and 2.4 are described in Table 2.1. The motors, propeller assemblies, and encoders are described in more detail below.

ID#	Description	ID#	Description
1	Helicopter body	11	Slip ring
2	Motor	12	Base
3	Front propeller assembly	13	Travel encoder
4	Back propeller assembly	14	Front motor connector
5	Pitch encoder	15	Back motor connector
6	Arm	16	Travel encoder connector
7	Elevation encoder frame	17	Pitch encoder connector
8	Elevation encoder	18	Elevation encoder connector
9	Counterweight	19	Motor connector
10	Encoder/motor circuit	20	Encoder connector

Table 2.1: 3 DOF Helicopter component nomenclature.

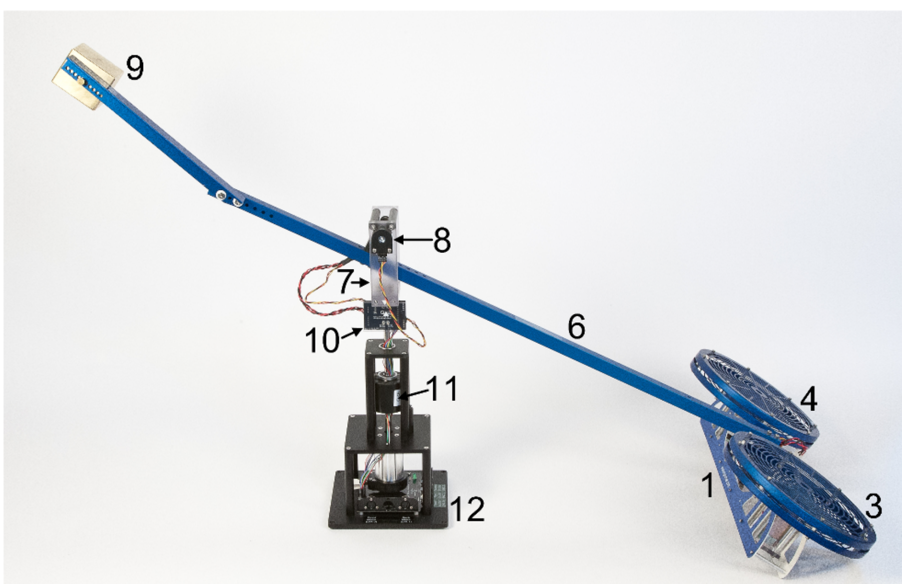


Figure 2.1: Components of the 3 DOF Helicopter.

2.1.2 DC Motors (Component #2)

The 3 DOF Helicopter has two DC motors: the front and back motors. Each DC motor is a Pittman Model 9234, with an electrical resistance of 0.83 Ω and a current-torque constant of 0.0182 N·m/A. The rated voltage of the motor is 12 V but its peak voltage can be brought up to 22 V without damage. See [1] for the full specifications of this motor.

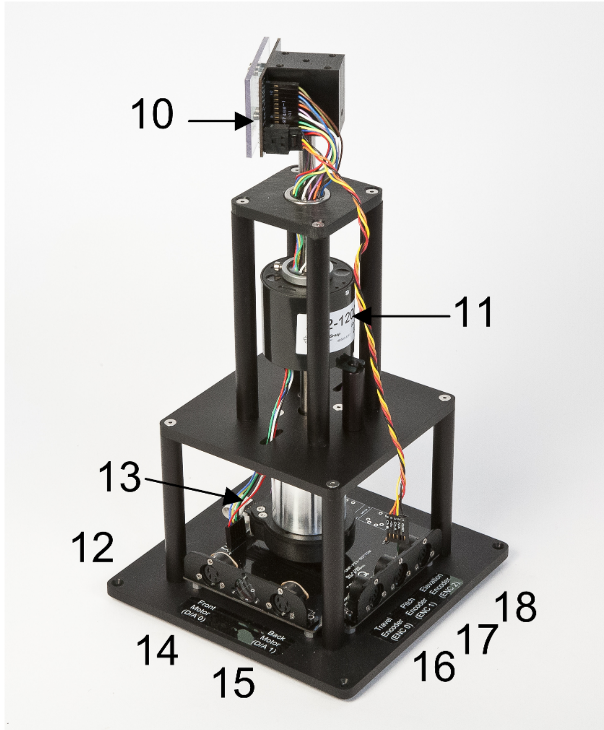


Figure 2.2: Components on the 3 DOF Helicopter base.

Figure 2.3: Components on the helicopter body of the 3 DOF Helicopter system.

Caution: Motor input: $\pm$24V, 5A peak, 3A continuous.

2.1.3 Propeller Assemblies (Components #3 and #4)

The front and back propeller assemblies are composed of the actual propeller, which is directly mounted to the motor shaft, and an aluminum propeller shield. The propellers used for both the front and rear motors are Graupner 20/15 cm or 8/6". They have an identified thrust-force constant of 0.119 N/V.

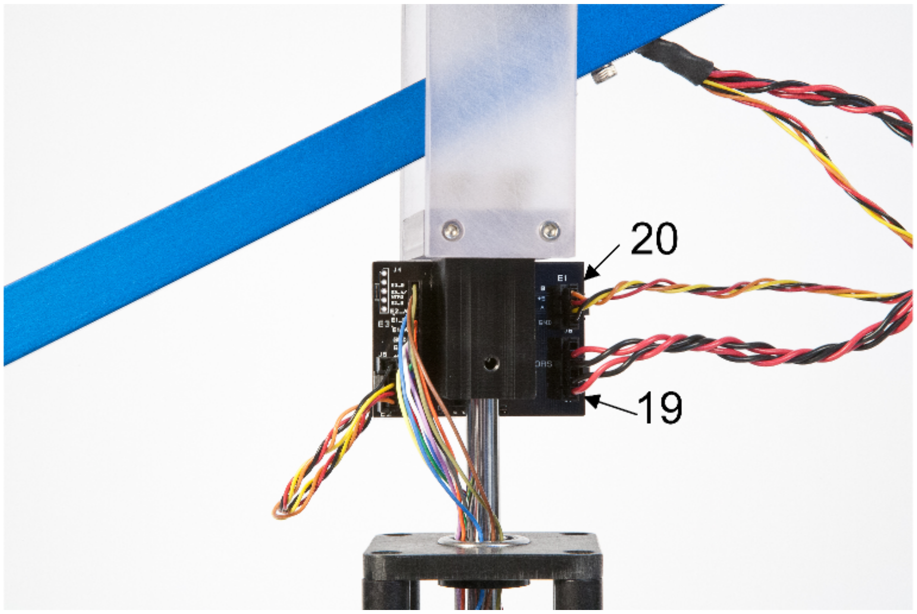


Figure 2.4: Encoder/motor circuit on the 3 DOF Helicopter pedestal.

⚠ **Caution:** The propellers rotate at high speeds. Always make sure the propeller shields are installed when in operation and stay clear of the system.

2.1.4 Encoders (Components #5, #8, and #14)

The 3 DOF Helicopter experiment has three encoders: the encoder measuring the pitch of the helicopter body, the encoder measuring the elevation of the body, and the encoder measuring the travel of the body. In quadrature mode, the pitch and elevation encoders have a resolution of 4096 counts per revolution and the travel encoder has a resolution of 8192 counter per revolution. Thus the effective position resolution is 0.0879 degrees about the pitch and elevation axes and 0.0439 degrees about the travel axis.

2.1.5 Active Disturbance System Components

The components of the Active Disturbance System (ADS) on the 3 DOF Helicopter system are labeled in Figures 2.5, 2.6, and 2.7 and the described in Table 2.1 and Table 2.2.

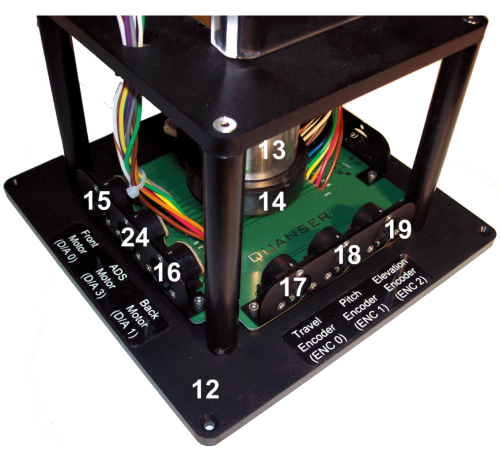


Figure 2.5: Connectors on base of 3 DOF Helicopter ADS experiment - ADS motor side view.

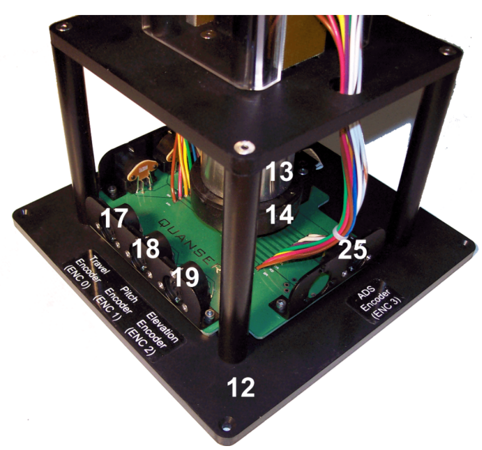


Figure 2.6: Connectors on base of 3 DOF Helicopter ADS experiment - ADS encoder side view.

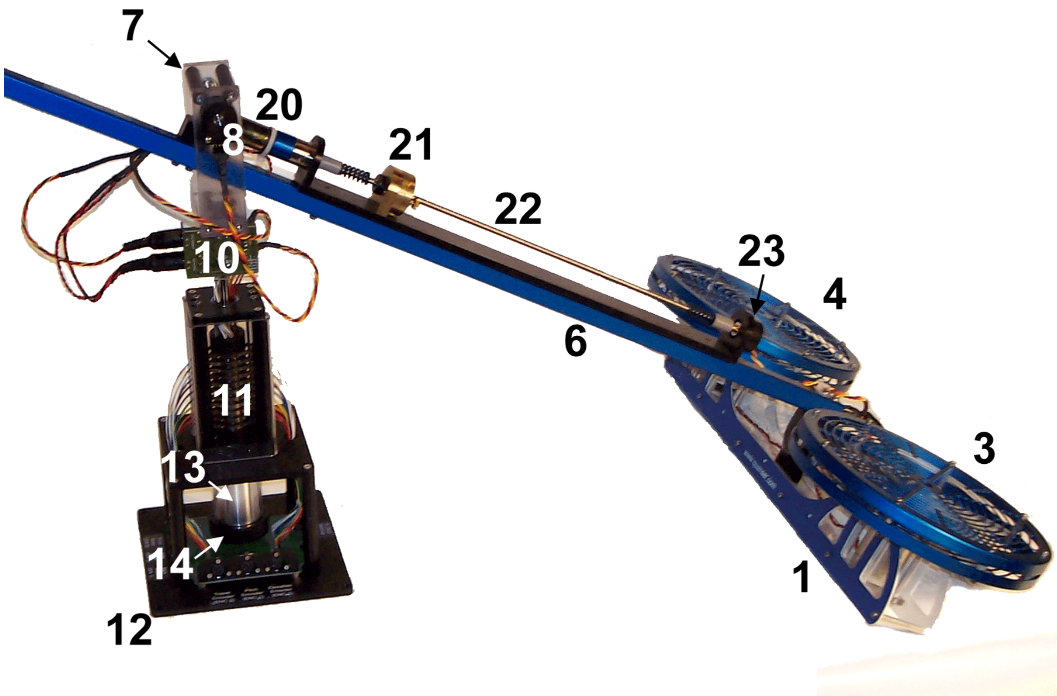


Figure 2.7: Components of the Active Disturbance System (ADS) on the 3 DOF Helicopter.

ID#	Description	ID#	Description
20	ADS Motor	23	ADS Encoder
21	Active Disturbance Mass	24	ADS Motor Connector
22	Lead-screw	25	ADS Encoder Connector

Table 2.2: Additional components on the 3 DOF Helicopter ADS experiment.

2.2 System Specifications

The 3 DOF Helicopter system specifications are given in Section 2.2.1 and the Active Disturbance System specifications are listed in Section 2.2.2.

2.2.1 3 DOF Helicopter Parameters

Table 2.3 below lists the main parameters associated with the Quanser 3 DOF Helicopter experiment.

Symbol	Description	Value	Unit
R_m	Motor armature resistance	0.83	Ω
K_t	Motor current-torque constant	0.0182	N·m/A
J_m	Motor rotor moment of inertia	1.91×10^{-6}	kg·m^2
K_f	Propeller force-thrust constant (found experimentally)	0.1188	N/V
M_h	Mass of the helicopter (body, two propeller assemblies, encoders, etc.)	1.15	kg
M_w	Mass of the counterweight	1.87	kg
M_f	Mass of front propeller assembly (includes motor, shield, propeller, and half helicopter body)	0.575	kg
M_b	Mass of back propeller assembly	0.713	kg
L_a	Distance between travel axis to helicopter body	0.660	m
L_h	Distance between pitch axis to each motor	0.178	m
L_w	Distance between travel axis to the counterweight	0.470	m
g	Gravitational constant	9.81	m/s^2
$K_{EC,LN,T}$	Travel encoder resolution (in quadrature mode)	8192	counts/rev
$K_{EC,LN,P}$	Pitch encoder resolution (in quadrature mode)	4096	counts/rev
$K_{EC,LN,E}$	Elevation encoder resolution (in quadrature mode)	4096	counts/rev
$K_{EC,T}$	Travel encoder calibration gain	7.67×10^{-4}	rad/counts
$K_{EC,P}$	Pitch encoder calibration gain	1.50×10^{-3}	rad/counts
$K_{EC,E}$	Elevation encoder calibration gain	-1.50×10^{-3}	rad/counts

Table 2.3: 3 DOF Helicopter system specifications.

2.2.2 ADS Parameters

Table 2.4 below describes the specifications of 3 DOF Helicopter Active Disturbance System.

Symbol	Description	Value	Unit
V_{nom}	Motor nominal input voltage	6.0	V
R_m	Motor armature resistance	2.6	Ω
L_m	Motor armature inductance	0.18	mH
K_t	Motor current-torque constant	0.00767	N·m/A
K_m	Motor back emf constant	0.00767	V·s/rad
J_m	Motor rotor moment of inertia	3.90×10^{-7}	kg·m^2
K_g	Internal gearbox gear ratio	3.71	
P_b	Lead-screw pitch	1/3	in/rev
x_{max}	Maximum travel limit of disturbance mass	0.264	m
v_{max}	Maximum speed of disturbance mass	0.25	m/s
$K_{EC,LN,X}$	ADS encoder resolution (in quadrature mode)	4096	counts/rev
$K_{EC,X}$	Calibration gain for linear position of disturbance mass	-2.067×10^{-6}	m/counts

Table 2.4: 3 DOF Helicopter Active Disturbance System specifications.

3 SYSTEM SETUP AND WIRING

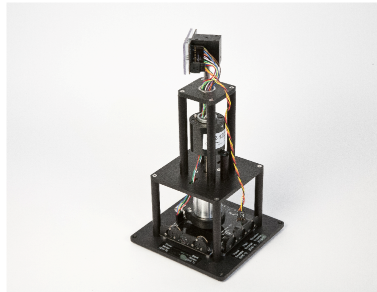
Section 3.1 describes how to assemble and setup the Quanser 3 DOF Helicopter specialty plant. The typical wiring procedure is given in Section 3.2. Section 3.3 features the additional connections needed if using the Active Disturbance System. Lastly, the joystick that can be used to control the helicopter is discussed in Section 3.4.

3.1 Assembling the 3 DOF Helicopter

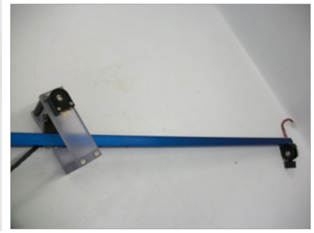
This section describes how to assemble the 3 DOF Helicopter. To avoid damaging or stressing the mechanical structure, the 3 DOF Helicopter is shipped in several pieces:

1. 3 DOF Helicopter body (shown in Figure 3.1a)
2. 3 DOF Helicopter pedestal (shown in Figure 3.1b)
3. 3 DOF Helicopter arm (shown in Figure 3.1c)
4. 3 DOF Helicopter tail (shown in Figure 3.1d)
5. 3 DOF Helicopter counterweight (shown in Figure 3.1e)
6. 1x Logitech USB joystick (shown in Figure 3.1f)
7. 3x 5-pin DIN to 5-pin DIN encoder cables (shown in Figure 3.1g)
8. 4x 8-32 3/4 inch brass thumb screws (shown in Figure 3.1h, may be installed on pedestal)
9. 1x 8-32 1/2 inch brass thumb screw (shown in Figure 3.1i, may be installed on counterweight or tail section)
10. 1x Allen key with 2x 8-32 1/2 inch cap screws (shown in Figure 3.1j, may be installed on body section)

(a) 3 DOF Helicopter body



(b) 3 DOF Helicopter pedestal

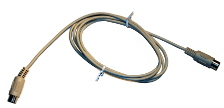


(c) 3 DOF Helicopter arm

(d) 3 DOF Helicopter tail

(e) Counterweight

(f) USB joystick



(g) Encoder cable

(h) 8-32 3/4 inch brass thumb screws

(i) 8-32 1/2 inch brass thumb screw

(j) Allen key and screws

Figure 3.1: 3 DOF Helicopter components.

To assemble the 3 DOF Helicopter , follow these steps:

1. Secure the pedestal to a solid surface. Failing to do this step, the 3 DOF Helicopter system might tip over when running the experiments. Ensure that the helicopter will not have obstructions that may interfere with the 360-degree axial motion.
2. Using the supplied 8-32 1/2 inch cap screws attach the helicopter body to the helicopter arm. Make sure the alignment arrows are facing each other as shown in Figure 3.2.

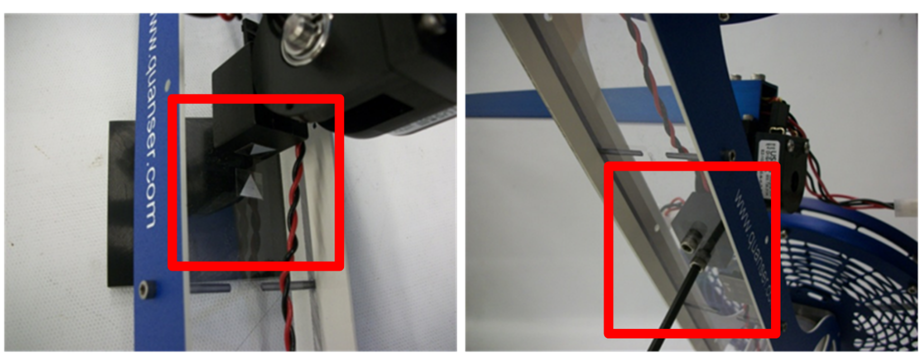


Figure 3.2: Attach the 3 DOF Helicopter body and arm.

Caution: Never apply extreme loads in the vertical direction!

3. Using the supplied 8-32 3/4 inch brass thumb screws, attach the 3 DOF Helicopter arm on the pedestal. Make sure the two alignment arrows are facing the same side as shown in Figure 3.3.

   ⚠ **Caution:** Once the body and arm are installed on the pedestal base, do not lift the system from the helicopter body or arm. Always carry from the base with one hand and stabilize the body with the other hand. Never apply extreme loads in the vertical direction!

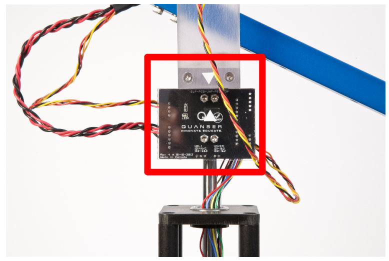


Figure 3.3: Attach the 3 DOF Helicopter arm to the pedestal.

4. Connect the four color encoder cable from the pedestal circuit board to the elevation encoder on the 3 DOF Helicopter body . Make sure that the ground pin on the encoder matches the ground terminal of the connector as shown in Figure 3.4.

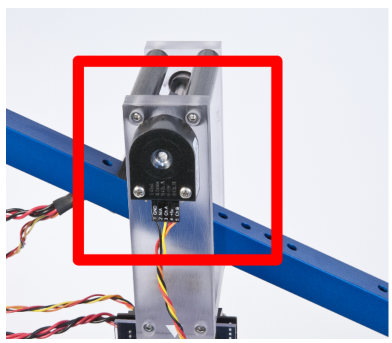


Figure 3.4: 3 DOF Helicopter encoder connection.

5. Connect the propeller command signals from the arm to the helicopter as shown in Figure 3.5.

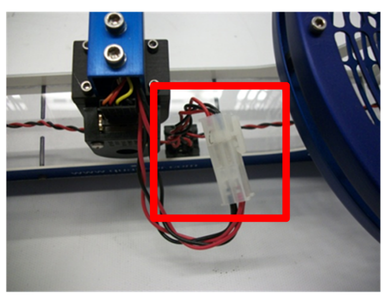


Figure 3.5: Connect the propeller command signals.

6. Using the screws and nuts attached to the rear section of the 3 DOF Helicopter arm, attach the tail as shown in Figure 3.6. Make sure to use the marked holes.

Figure 3.6: Connect the 3 DOF Helicopter tail.

7. Connect the 4-pin rectangular encoder connector and the 6-pin rectangular motor connector from the 3 DOF Helicopter arm to the pedestal circuit board as shown in Figure 3.7.

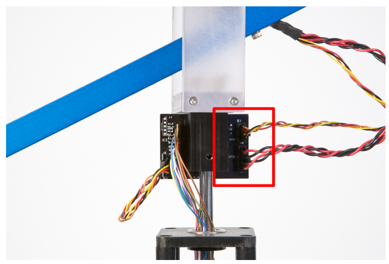


Figure 3.7: Connect the motor and encoder to the 3 DOF Helicopter circuit board.

8. The standard setup, in the default configuration, and starting position for the 3 DOF Helicopter system is depicted in Figure 3.8.

   Caution: Exposed moving parts. Ensure all obstructions that may interfere with the complete 360-degree axial motion of the helicopter are removed before performing any experiment.

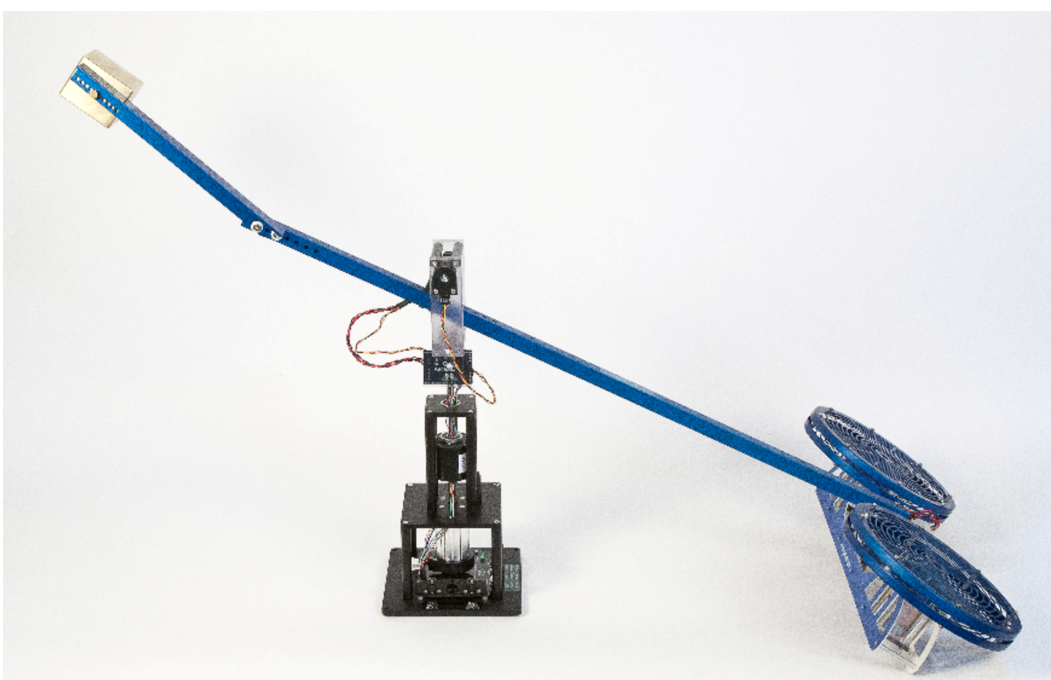


Figure 3.8: Starting position of the 3 DOF Helicopter system.

3.2 Typical Connections for the 3 DOF Helicopter

This section describes the typical cabling connections that are used by default for the Quanser 3 DOF Helicopter system. The travel, pitch, and elevation encoders are connected directly to the data-acquisition board. This provides the position feedback necessary to control the helicopter. The data-acquisition board, i.e., DAQ board, outputs a control voltage that is amplified and drives the front and back motors. Both motors are driven by a power amplifier, e.g. such as the Quanser VoltPAQ-X2 or two VoltPAQ-X1 systems. Figure 3.9 illustrates the wiring between the two-channel data-acquisition device, the 3 DOF Helicopter base, and a two-channel amplifier. These connections are described in detail in Section 3.2.1 and summarized in Table 3.1.

Caution: If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Caution: If you have an Emergency Stop, then it is highly recommended that you connect it to your VoltPAQ amplifier.

Note: Your configuration may be different. For instance, you may have a DAQ with more IOs than the one presented in Figure 3.9 or have two single-channel amplifiers that do not require any E-Stop (in which case you would omit connection).

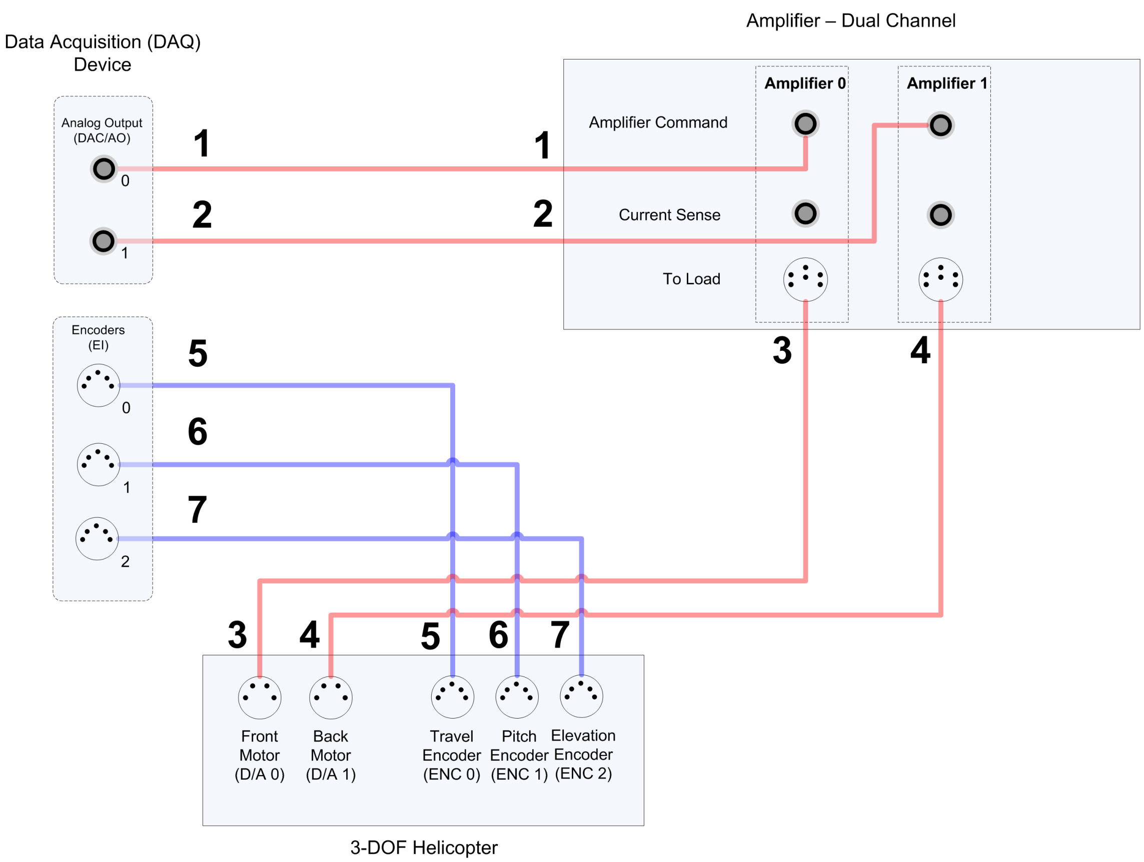


Figure 3.9: 3 DOF Helicopter connection diagram

Cable	From	To	Signal
1	Terminal Board: **Analog Output #0**	Amplifier 0: **Command**	Command signal sent to amplifier for the front motor.
2	Terminal Board: **Analog Output #1**	Amplifier 1: **Command**	Command signal sent to amplifier for the back motor.
3	Amplifier 0: **To Load**	3 DOF Helicopter: **Front Motor (D/A 0)**	Amplified voltage that is applied to the front DC motor.
4	Amplifier 1: **To Load**	3 DOF Helicopter: **Back Motor (D/A 1)**	Amplified voltage that is applied to the back DC motor.
5	3 DOF Helicopter: **Travel Encoder (ENC 0)**	Terminal Board: **Encoder Channel #0**	Measured travel angle.
6	3 DOF Helicopter: **Pitch Encoder (ENC 1)**	Terminal Board: **Encoder Channel #1**	Measured pitch angle.
7	3 DOF Helicopter: **Elevation Encoder (ENC 2)**	Terminal Board: **Encoder Channel #2**	Measured elevation angle.
8	**Emergency Stop switch**	Amplifier: **E-Stop connector**	Emergency Stop signal.

Table 3.1: 3 DOF Helicopter system wiring summary

3.2.1 Wiring Details

Follow these steps to connect the 3 DOF Helicopter system:

1. Make sure your data acquisition (DAQ) device has been installed and tested. See the specific DAQ documentation for details.
2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the amplifiers.
3. Connect the 2xRCA to 2xRCA cable from the *Analog Output Channel #0* on the terminal board to the Amplifier 0 *Amplifier Command* connector. This is illustrated by connection #1 in Figure 3.9.
4. Connect the 2xRCA to 2xRCA cable from the *Analog Output Channel #1* on the terminal board to the Amplifier 1 *Amplifier Command* connector. This is illustrated by connection #2 in Figure 3.9.
5. Connect a 4-pin-DIN to 6-pin-DIN cable from the Amplifier 0 *To Load* connector to the *Front Motor (D/A 0)* connector on the 3 DOF Helicopter plant. This is illustrated by connection #3 in Figure 3.9.
6. Connect a 4-pin-DIN to 6-pin-DIN cable from the Amplifier 1 *To Load* connector to the *Back Motor (D/A 1)* connector on the 3 DOF Helicopter plant. This is illustrated by connection #4 in Figure 3.9.
7. Connect a 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder 0* connector on the terminal board to the *Travel Encoder (ENC 0)* connector on the 3 DOF Helicopter base. This is illustrated by connection #5 in Figure 3.9.

   Caution: Any encoder should be directly connected to the Quanser terminal board (or equivalent) using a standard 5-pin DIN cable. DO NOT connect the encoder cable to the amplifier!

8. Connect another 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder 1* connector on the terminal board to the *Pitch Encoder (ENC 1)* connector on the 3 DOF Helicopter plant. This is illustrated by connection #6 in Figure 3.9.

9. Connect another 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder 2* connector on the terminal board to the *Elevation Encoder (ENC 2)* connector on the 3 DOF Helicopter plant. This is illustrated by connection #7 in Figure 3.9.
10. Connect the emergency stop switch to the E-Stop connector on the amplifier. This is illustrated by connection #8 in Figure 3.9.
11. Connect the USB cable from the Logitech Attack 3 USB joystick shown in Figure 3.1f to a USB port on the PC. The system should detect the joystick and automatically install the driver (you will be prompted). See the *Logitech Installation Manual* for more information on the setup procedure. See Section 3.4 for more information on system requirements of the Logitech joystick and how to use the *Rate Command* knob.
12. If your amplifier has a Gain setting switch, make sure you set the amplifier Gain to 3 when using the 3 DOF Helicopter experiment.
13. Turn ON the rear power switch of the amplifier.

3.3 Additional Connections for the 3 DOF Helicopter w/ ADS

The additional wiring needed to operate the Active Disturbance System (ADS) is detailed in this section. The full connections between the DAQ terminal boards, amplifiers, and 3 DOF Helicopter with the ADS option are illustrated in Figure 3.10. These connections are described in detail in the procedure below and summarized in Table 3.2.

Note: When using VoltPAQ-X1, make sure the gain is set to 3.

Cable #	From	To	Signal
8	DAQ: Analog Output #2	Amplifier 2 *Amplifier Command* connector	Control signal to the ADS.
9	Amplifier 2 *To Load* connector #1	3 DOF Helicopter *ADS Motor (D/A 2)* connector	Power leads to the 3 DOF Helicopter's ADS DC motor.
10	3 DOF Helicopter *ADS Encoder (ENC 3)* connector	Terminal Board: Encoder Channel #3	Active Mass Disturbance lead-screw angle feedback signal to the data acquisition card.

Table 3.2: Additional wiring summary for 3 DOF Helicopter with Active Mass Disturbance system.

Follow these steps to connect the 3 DOF Helicopter with the Active Disturbance System (ADS) experiment:

1. Go through the 3 DOF Helicopter wiring as dictated in Section 3.2.
2. Connect the 2xRCA to 2xRCA cable from the *Analog Output Channel #2* on the DAC board to the *Amplifier Command* connector on the amplifier. See cable #8 shown in Figure 3.10. This carries the attenuated ADS motor voltage control signal, $V_a ds/K_a$, where K_a is the amplifier gain.
3. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN from *To Load* on the amplifier to the **ADS** motor connector. See connection #9 shown in Figure 3.10. The cable transmits the amplified voltage that is applied to the ADS motor, $V_a ds$.
4. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *ADS Encoder* connector on the 3 DOF Helicopter base to *Encoder Input #3* on the terminal board, as depicted by connection #10 in Figure 3.10. This carries the angular measurement of the ADS lead screw. This measurement is then translated to give the linear position of the disturbance mass and is denoted by the variable x.

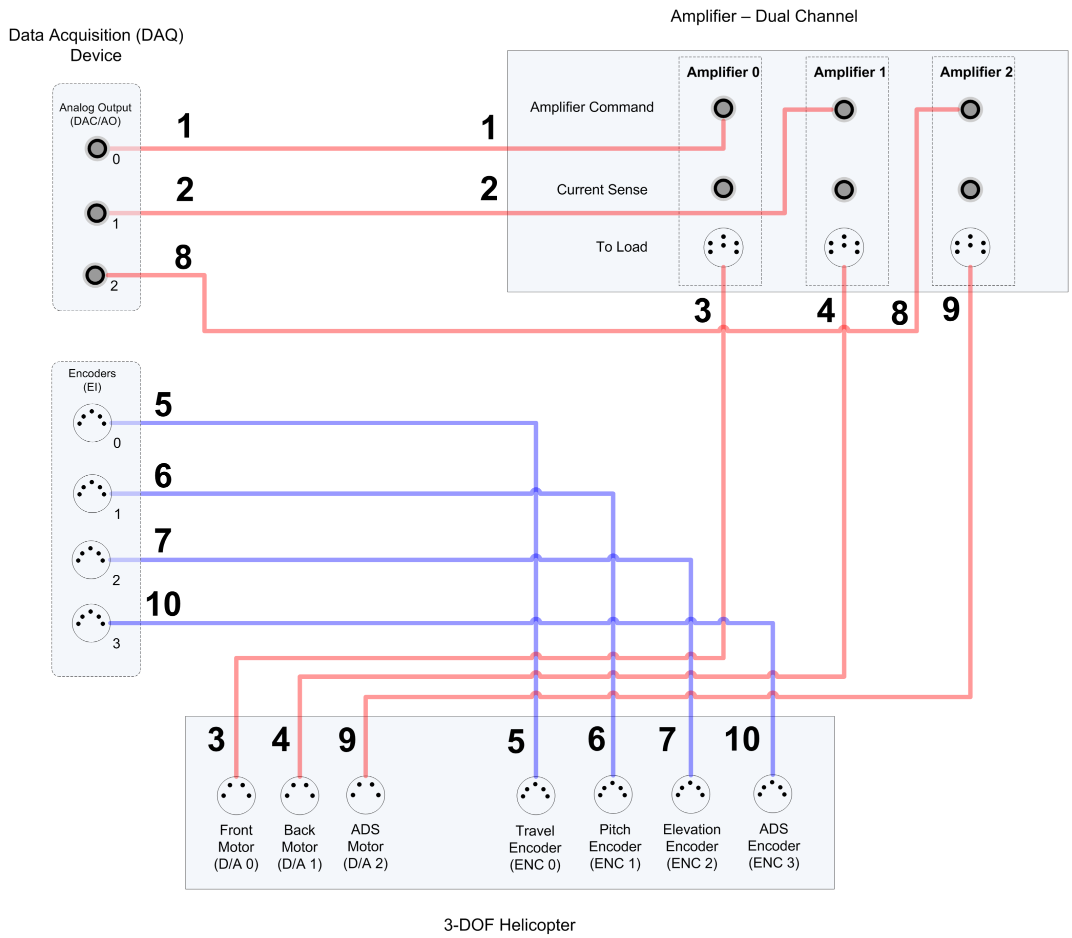


Figure 3.10: Connection diagram for 3 DOF Helicopter with the ADS option.

3.4 Joystick Description

The Quanser 3 DOF Helicopter experiment is supplied with a Logitech Extreme 3D Pro joystick shown in Figure 3.1f. The joystick can be used to generate a desired position directly, instead of via the Simulink model blocks (see lab procedure).

Figure 3.11: Logitech Attack-3 USB joystick.

The setup procedure for the USB joystick is described in step 10 in Section 3.2. The rate command knob shown in Figure 3.11 changes the rate at which a command is generated by the joystick. The rate is at its greatest when the knob is turned fully toward the joystick handle.

4 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your system is operating normally. It is assumed that the 3 DOF Helicopter is connected as described in Section 3. To carry out these tests, it is preferable if the user can use a software such as QUARC® or LabVIEW™ to read sensor measurements and feed voltages to the motor. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

4.1 Motor

4.1.1 Testing

Ensure the motors are operating correctly by going through this procedure:

1. Apply approximately 4V to Analog Output Channel #0 of the terminal board to test the **front** motor and verify that the propeller rotates.
2. Similarly, apply 4V to Analog Output Channel #1 to drive the **back** motor and verify that the propeller rotates.

4.1.2 Troubleshooting

If the motor is not responding to a voltage signal, go through these steps:

- Verify that the power amplifier is functional. For example when using the Quanser VoltPAQ device, is the green LED lit?
- Check that the data-acquisition board is functional, e.g. ensure it is properly connected, that the fuse is not burnt.
- Make sure the voltage is actually reaching the motor terminals (use a voltmeter or oscilloscope).
- If the motor terminals are receiving the signal and the motor is still not turning, your motor might be damaged and will need to be repaired. Please see 5 for information on contacting Quanser for technical support.

4.2 Encoder

4.2.1 Testing

Follow this procedure to test each encoder on their respective motors:

1. Measure the Encoder Input Channel #0 and rotate the travel angle. This encoder measures 8192 counts per full revolution. Rotate the helicopter body one full rotation and verify that 8192 is being measured.
2. Measure Encoder Input Channel #1 and rotate the pitch angle by moving the helicopter nose (i.e., front propeller) up and down. This encoder measures 4096 counts for every revolution. Moving it from the horizontal position to the highest "upward" or lowest "downward" position, roughly ± 90 °, should therefore read around 1024 counts.
3. Similarly, measure Encoder Input Channel #2 and elevate the helicopter from its lowest initial position to a horizontal position. Given that the initial position of the helicopter is at an angle of -27.5 °, approximately 313 counts should be read.

Note: Some data acquisition systems do not measure in quadrature and, in this case, one-quarter of the expected counts are received, i.e. 1024 counts in the pitch. In addition, some data acquisition systems measure in quadrature but increment the count by 0.25 (as opposed to having an integer number of counts). Make sure the details of the data-acquisition system being used is known. The counters on the Quanser DAQ boards measure in quadrature and therefore a total of four times the number of encoder lines per rotation, e.g. a 1024-line encoder results in 4096 integer counts for every full rotation.

4.2.2 Troubleshooting

If the encoder is not measuring properly, go through this procedure:

- Check that the data-acquisition board is functional, e.g. ensure it is properly connected, that the fuse is not burnt.
- Check that both the A and B channels from the encoder are properly generated and fed to the data-acquisition device. Using an oscilloscope, there should be two square waves, signals A and B, with a phase shift of 90 degrees. If this is not observed then the encoder may be damaged and need to be replaced. Please see section 5 for information on contacting Quanser for technical support.

5 TECHNICAL SUPPORT

To obtain support from Quanser, go to http://www.quanser.com/ and click on the Tech Support link. Fill in the form with all the requested software and hardware information as well as a description of the problem encountered. Also, make sure your e-mail address and telephone number are included. Submit the form and a technical support representative will contact you.

REFERENCES

[1] Pittman. *LO COG DC Servo Motor Series 8000, 9000, and 14000*, 2002.

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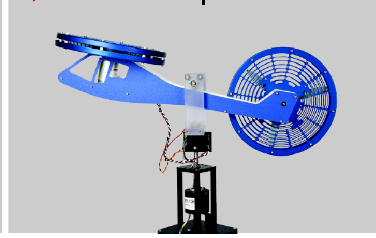
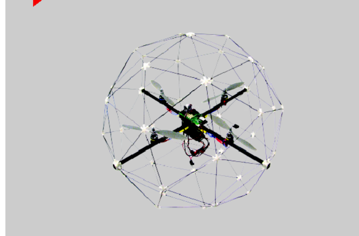
3 DOF Helicopter

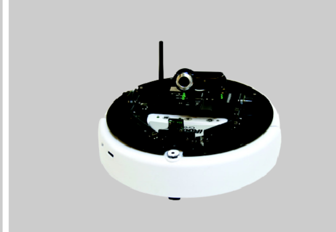


2 DOF Helicopter

3 DOF Hover



Qball-X4



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