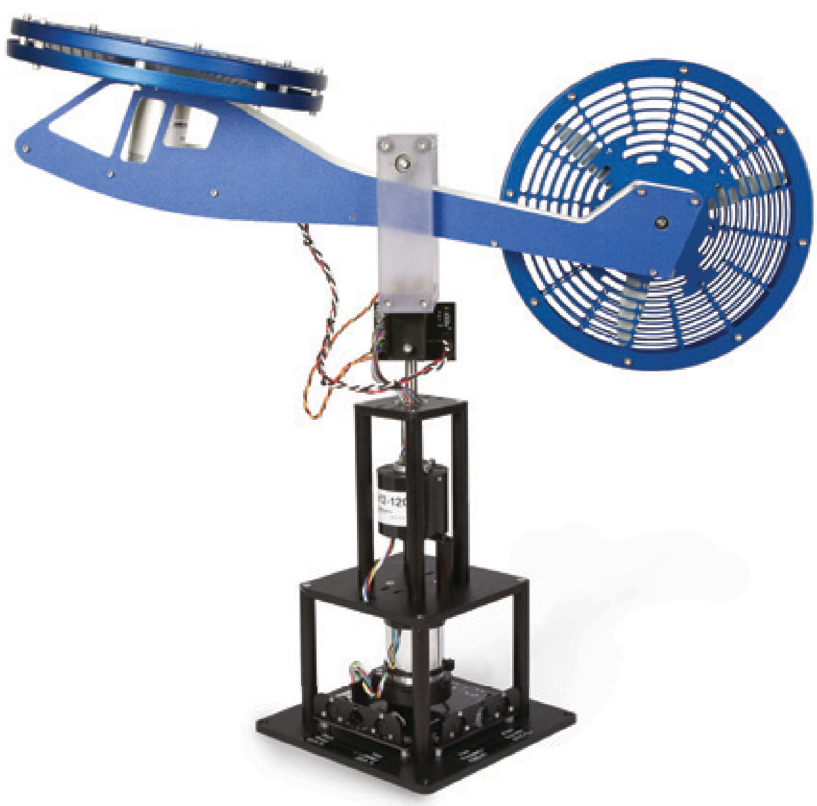
USER MANUAL

2 DOF Helicopter Experiment

Set Up and Configuration



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CONTENTS

1 PRESENTATION

The Quanser 2 DOF Helicopter experiment, shown in Figure 1.1, consists of a helicopter model mounted on a fixed base with two propellers that are driven by DC motors. The front propeller controls the elevation of the helicopter nose about the pitch axis and the back propeller controls the side to side motions of the helicopter about the yaw axis. The pitch and yaw angles are measured using high-resolution encoders. The pitch encoder and motor signals are transmitted via a slipring. This eliminates the possibility of wires tangling on the yaw axis and allows the yaw angle to rotate freely about 360 degrees.

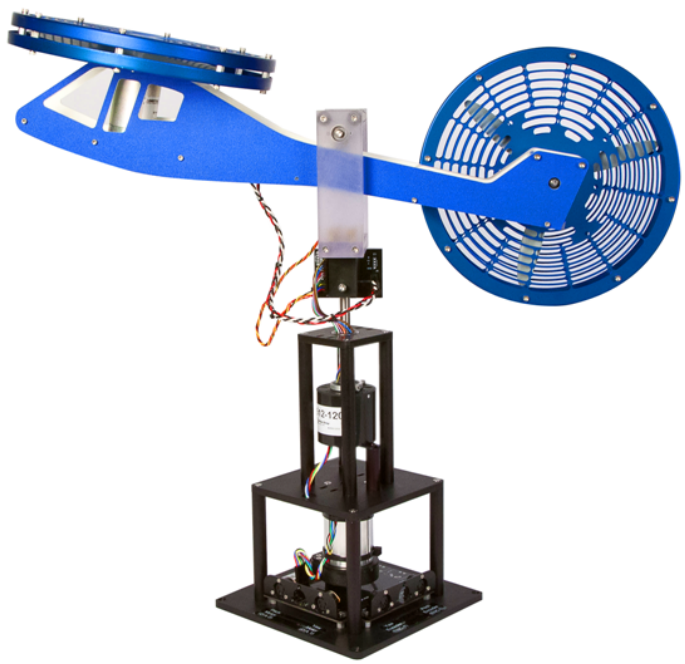


Figure 1.1: Quanser 2 DOF Helicopter

In Section 2 the components composing the 2 DOF Helicopter are described and the system specifications are given. Section 3 explains how to setup the system and gives the wiring procedure.

■ **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.

2 SYSTEM DESCRIPTION

2.1 Components

Section 2.1.1 lists the components on the 2 DOF Helicopter plant and 2.2 summarizes the system specifications.

2.1.1 2 DOF Helicopter Overall Components

The components comprising the 2 DOF Helicopter system are labeled in Figure 2.1, Figure 2.2, Figure 2.3, Figure 2.4, Figure 2.5 and Figure 2.6, are described in Table 2.1. The motors, propeller assemblies, and encoders are described in more detail below.

ID #	Component	ID #	Component
1	Back propeller	11	Encoder connector on circuit
2	Back propeller shield	12	Motor connector on circuit
3	Yaw/back motor	13	Metal shaft rotates about yaw axis
4	Pitch encoder	14	Slip ring
5	Yoke	15	Base platform
6	Helicopter body	16	Pitch motor connector
7	Front propeller	17	Yaw motor connector
8	Pitch/front motor	18	Yaw encoder connector
9	Front propeller shield	19	Pitch encoder connector
10	Encoder/motor circuit		

Table 2.1: 2 DOF Helicopter components

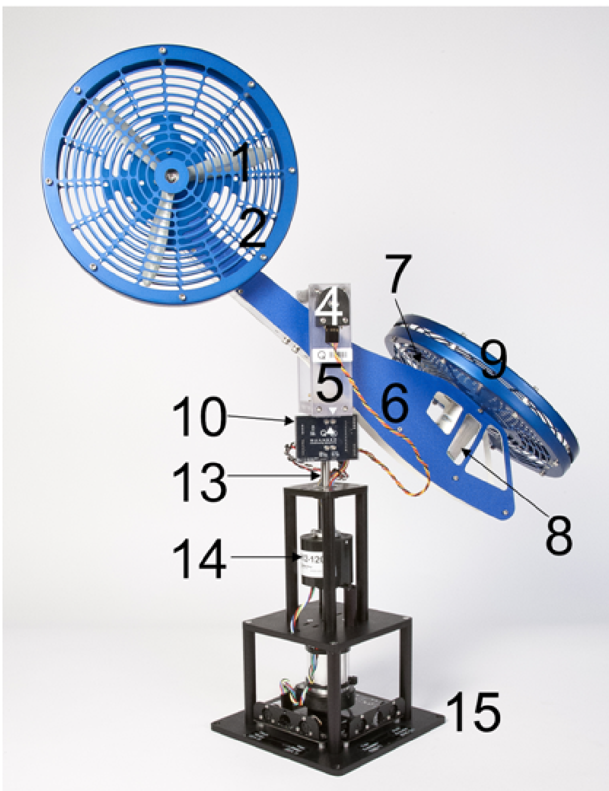


Figure 2.1: 2 DOF Helicopter components

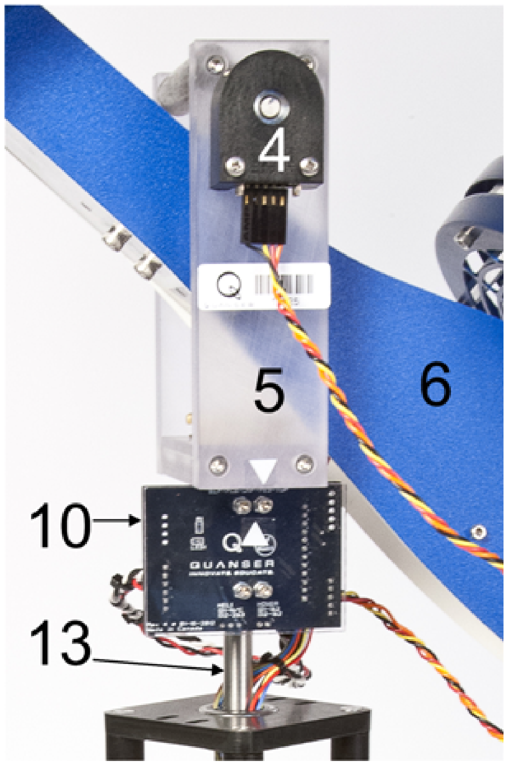


Figure 2.2: 2 DOF Helicopter yoke components

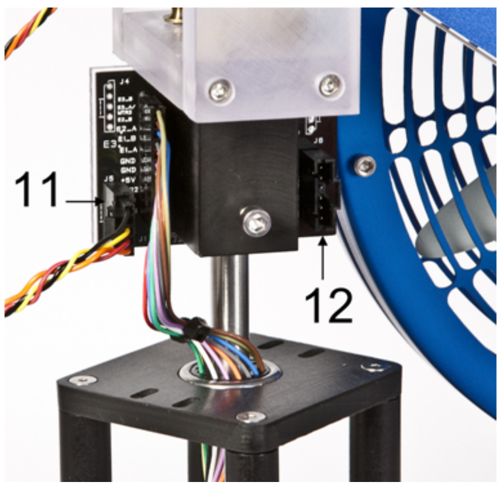


Figure 2.3: 2 DOF Helicopter circuit components

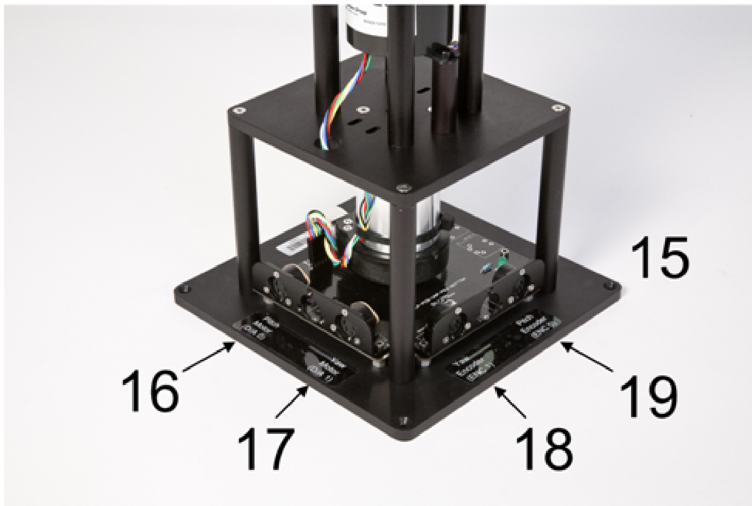


Figure 2.4: 2 DOF Helicopter base components

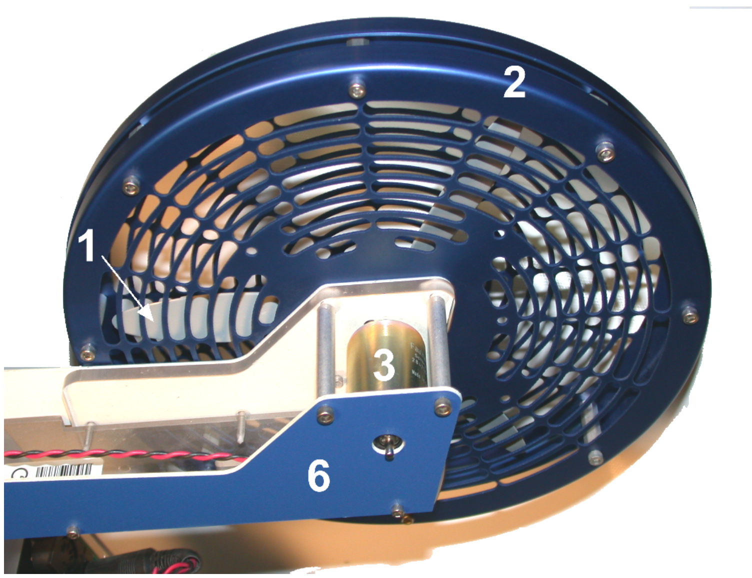


Figure 2.5: 2 DOF Helicopter tail components

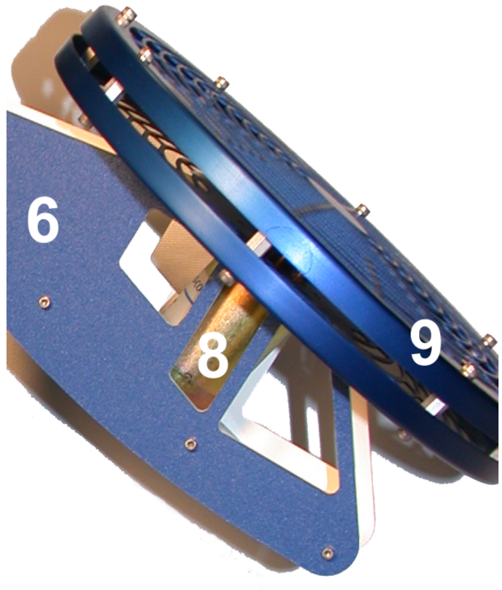


Figure 2.6: 2 DOF Helicopter front propeller assembly components

2.1.2 DC Motors (Components #3 and #8)

The 2 DOF Helicopter has two DC motors: the yaw motor, component #3, actuating the back propeller and the pitch motor, component #8, rotating the front propeller.

The yaw motor is a Faulhaber Series 2842 Model 006C motor. It has a terminal resistance of 1.6 Ω and a current-torque constant of 0.0109 N.m/A. See [1] for the full specifications of this motor. The larger pitch motor is a Pittman Model 9234. It has 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 [2] for the full specifications of this motor.

■ **Caution: Pitch motor input: ±24V, 5A peak, 3A continuous. Yaw motor: ±15V, 3A peak, 1A continuous.**

2.1.3 Propellers (Components #1 and #7)

The pitch and yaw propeller assemblies are composed of the actual propeller, which is directly mounted to the motor shaft, and the aluminum propeller shield. The propellers used for both the pitch and yaw motors are Graupner 20/15 cm or 8/6". The pitch motor/propeller has an identified thrust-force constant of 0.104 N/V and the yaw motor/propeller has a thrust-force constant of 0.43 N/V.

■ **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 #4 and #15)

The 2 DOF Helicopter experiment has two encoders: the encoder measuring the pitch angle, component #4, and the encoder measuring the yaw angle. In quadrature mode, the pitch encoder has a resolution of 4096 counts per revolution and the yaw encoder has a resolution of 8192 counter per revolution. Thus the effective position resolution is 0.0879 degrees about the pitch axis and 0.0439 degrees about the yaw axis

2.2 System Specifications

The main parameters of the 2 DOF Helicopter is summarized in Table 2.2. The motor and encoder specifications are listed in Table 2.3 below. Finally, Table 2.4 lists various dimensions, masses, and inertias of the 2 DOF Helicopter system.

Symbol	Description	Value	Unit
K_{pp}	Thrust force constant of yaw motor/propeller	0.204	N.m/V
K_{yy}	Thrust torque constant of yaw axis from yaw motor/propeller	0.072	N.m/V
K_{py}	Thrust torque constant acting on pitch axis from yaw motor/propeller	0.0068	N.m/V
K_{yp}	Thrust torque constant acting on yaw axis from pitch motor/propeller	0.0219	N.m/V
$B_{eq,p}$	Equivalent viscous damping about pitch axis	0.800	N/V
$B_{eq,y}$	Equivalent viscous damping about yaw axis	0.318	N/V
m_{heli}	Total moving mass of the helicopter (body, two propeller assemblies, etc.)	1.3872	kg
l_{cm}	Center of mass length along helicopter body from pitch axis	0.186	m
$J_{eq,p}$	Total moment of inertia about pitch axis	0.0384	kg.m^2
$J_{eq,y}$	Total moment of inertia about yaw axis.	0.0432	kg.m^2

Table 2.2: 2 DOF Helicopter model parameters

Symbol	Description	Value	Unit
$R_{m,p}$	Armature resistance of pitch motor	0.83	Ω
$R_{m,y}$	Armature resistance of yaw motor	1.60	Ω
$K_{t,p}$	Current-torque constant of pitch motor	0.0182	N.m/A
$K_{t,y}$	Current-torque constant of yaw motor	0.0109	N.m/A
$J_{m,p}$	Rotor moment of inertia of pitch motor	1.91×10^{-6}	kg.m^2
$J_{m,y}$	Rotor moment of inertia of yaw motor	1.37×10^{-4}	kg.m^2
$K_{f,p}$	Pitch propeller force-thrust constant (found experimentally)	0.1037	N/V
$K_{f,y}$	Yaw propeller force-thrust constant (found experimentally)	0.428	N/V
$m_{m,p}$	Mass of pitch motor	0.292	kg
$m_{m,y}$	Mass of yaw motor	0.128	kg
$K_{EC,LN,Y}$	Yaw encoder resolution (in quadrature mode)	8192	counts/rev
$K_{EC,LN,P}$	Pitch encoder resolution (in quadrature mode)	4096	counts/rev
$K_{EC,Y}$	Yaw encoder calibration gain	7.67×10^{-4}	rad/counts
$K_{EC,P}$	pitch encoder calibration gain	1.50×10^{-3}	rad/counts

Table 2.3: 2 DOF Helicopter motor and encoder specifications

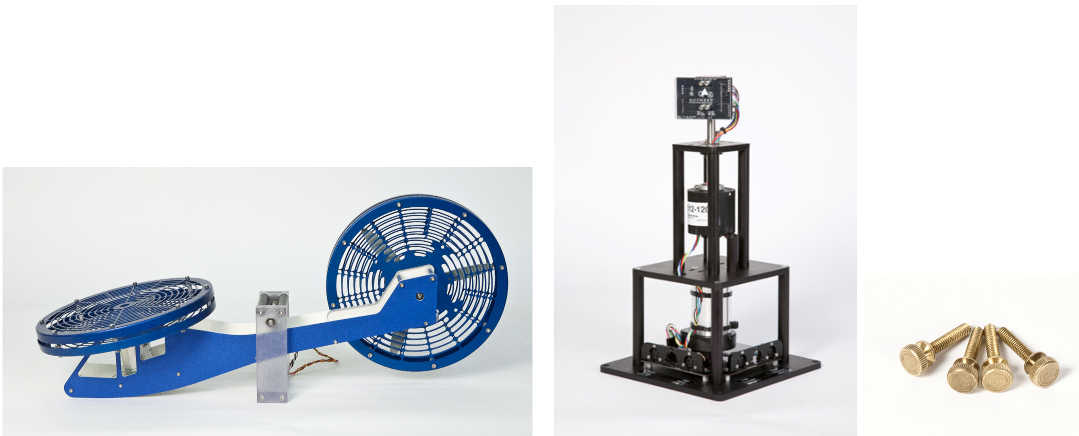
Symbol	Description	Value	Unit
m_{shield}	Mass of propeller shield	0.167	kg
m_{props}	Mass of pitch and yaw propellers, propeller shields, and motors	0.754	kg
$m_{body,p}$	Mass moving about pitch axis	0.633	kg
$m_{body,y}$	Mass moving about yaw axis	0.667	kg
m_{shaft}	Mass of metal shaft rotating about yaw axis	0.151	kg
L_{body}	Total length of helicopter body	0.483	m
L_{shaft}	Length of metal shaft rotating about yaw axis	0.280	m
$J_{body,p}$	Moment of inertia of helicopter body about pitch axis	0.0123	kg.m^2
$J_{body,y}$	Moment of inertia of helicopter body about yaw axis	0.0129	kg.m^2
J_{shaft}	Moment of inertia of metal shaft about yaw axis end point	0.0039	kg.m^2
J_p	Moment of inertia of front motor/shield assembly about pitch pivot	0.0178	kg.m^2
J_y	Moment of inertia of back motor/shield assembly about yaw pivot	0.0084	kg.m^2

Table 2.4: Various 2 DOF Helicopter mass, length, and inertia parameters

3 SYSTEM SETUP

3.1 Assembling the 2 DOF Helicopter

This section describes how to assemble the 2 DOF Helicopter. To avoid damaging or stressing the mechanical structure, the 2 DOF Helicopter is shipped in two pieces: the body and the pedestal, as shown in Figure 3.1a and Figure 3.1b.



(a) 2 DOF Helicopter body (b) 2 DOF Helicopter pedestal (c) 8-32 Brass Thumb Screws

Figure 3.1: 2 DOF Helicopter assembly components

Follow these steps to assemble the 2 DOF Helicopter:

1. Secure the pedestal to a solid surface. Failing to do this step, the 2 DOF Helicopter system might tip over when running the experiments.
2. Using the supplied 8-32 brass thumb screws, attach the 2 DOF Helicopter body on the pedestal. Make sure the two alignment arrows are facing the same side (shown in Figure 3.2).

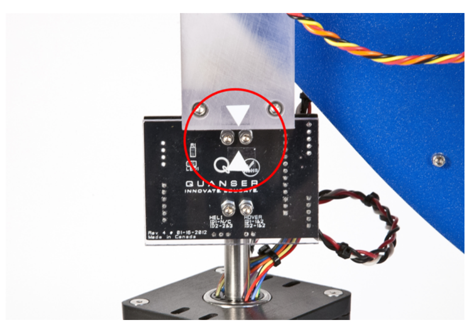


Figure 3.2: Align the 2 DOF Helicopter pedestal and body

3. Using the four color cable in the pedestal, connect the pitch encoder on the 2 DOF Helicopter body to the pedestal. Make sure that the ground pin on the encoder matches the ground terminal of the connector (shown in Figure 3.3).

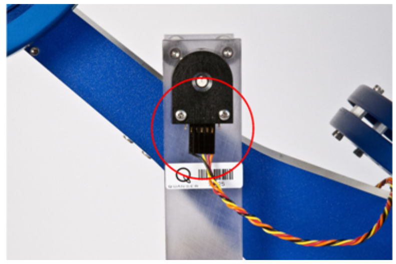


Figure 3.3: Connect the encoder cable

4. Connect the motor cable from the 2 DOF Helicopter to the 6-pin rectangular connector labeled **MOTORS** on the pedestal circuit board (shown in Figure 3.4).

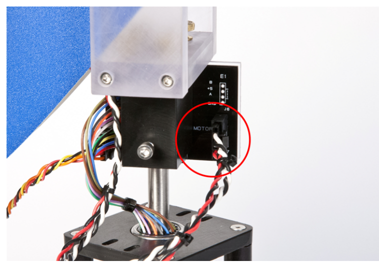


Figure 3.4: Connect the motor connector

3.2 Typical Connections for the 2 DOF Helicopter

This section describes the typical cabling connections that are used by default for the Quanser 2 DOF Helicopter system. The yaw and pitch 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. Figure 3.5 illustrates the wiring between the two-channel data-aquisition device, the 2 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.

Note: It is assumed that an Emergency Stop has to be connected to the amplifier. Your configuration may be different. For instance, you may have a DAQ with more IOs than the one presented in Figure 3.5 or have two single-channel amplifiers that do not require any E-Stop (in which case, you would omit connection #7).

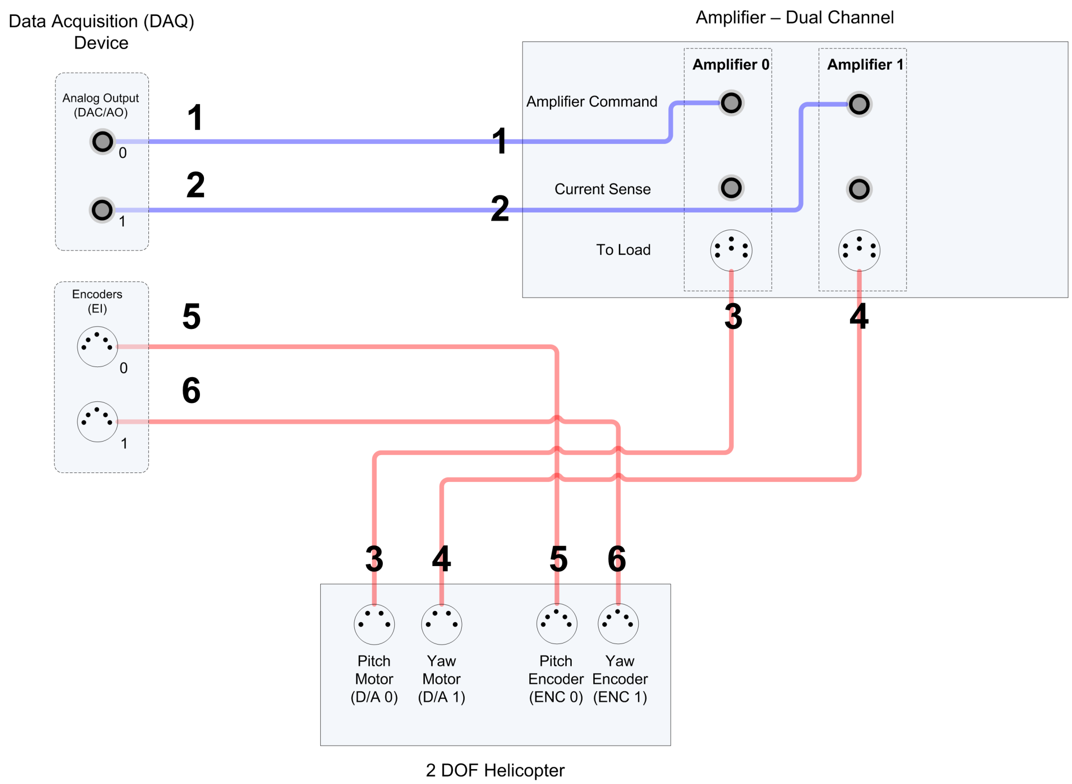


Figure 3.5: Typical connections of the 2 DOF Helicopter Experiment

Cable #	From	To	Signal
1	Terminal Board: **Analog Output #0**	Amplifier 0: **Command**	Command signal sent to amplifier for the pitch motor.
2	Terminal Board: **Analog Output #1**	Amplifier 1: **Command**	Command signal sent to amplifier for the yaw motor.
3	Amplifier 0: **To Load**	2 DOF Helicopter: **Pitch Motor (D/A 0)**	Amplified voltage that is applied to the pitch DC motor.
4	Amplifier 1: **To Load**	2 DOF Helicopter: **Yaw Motor (D/A 1)**	Amplified voltage that is applied to the yaw DC motor.
5	2 DOF Helicopter: **Pitch Encoder (ENC 0)** connector	Terminal Board: **Encoder Channel #0**	Measured pitch angle.
6	2 DOF Helicopter: **Yaw Encoder (ENC 1)** connector	Terminal Board: **Encoder Channel #1**	Measured yaw angle.

Table 3.1: 2 DOF Helicopter system wiring summary

3.2.1 Wiring Details

Follow these steps to connect the 2 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 amplifier.

3. Connect one of the connectors on the 2x RCA to 2x RCA 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 3.5.

4. Connect the other line of the 2XRCA to 2XRCA cable from the *Analog Output #1* connector on the terminal board to the Amplifier 1 *Amplifier Command* connector. This is illustrated by connection #2 in Figure 3.5.

5. Connect a 4-pin-DIN to 6-pin-DIN cable from Amplifier 0 *To Load (3x Amplifier Command)* connector, to the *Pitch Motor (D/A 0)* connector on the 2 DOF Helicopter plant. This is illustrated by connection #3 in Figure 3.5.

6. Connect another 4-pin-DIN to 6-pin-DIN cable from the Amplifier 1 *To Load (3x Amplifier Command)* connector, to the *Yaw Motor (D/A 1)* connector on the 2 DOF Helicopter plant. This is illustrated by connection #4 in Figure 3.5.

7. Connect a 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder 0* connector on the terminal board, to the *Pitch Encoder (ENC 0)* connector on the 2 DOF Helicopter plant. This is illustrated by connection #5 in Figure 3.5.

8. Connect another 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder 1* connector on the terminal board to the *Yaw Encoder (ENC 1)* connector on the 2 DOF Helicopter plant. This is illustrated by connection #6 in Figure 3.5.

   ■ **Caution:** 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 amplifiers!

9. Connect the USB cable from the Logitech Attack 3 USB joystick shown in Figure 3.6 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 3.3 for more information on system requirements of the Logitech joystick and how to use the *Rate Command* knob.

10. If your amplifier has a Gain setting switch, make sure you set the amplifier Gain to 3 when using the 2 DOF Helicopter experiment.

11. Turn ON the rear power switch of the amplifier.

3.3 Joystick Description

The Quanser 2 DOF Helicopter experiment is supplied with a Logitech Extreme 3D Pro joystick, shown in Figure 3.6. The joystick can be used in software, for instance, to generate the desired helicopter position.

Figure 3.6: Logitech Attack-3 USB joystick

The setup procedure for the USB joystick is described in 3.2. The rate command knob shown in Figure 3.6 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 2 DOF Helicopter is connected as described in Section 3.2. 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 pitch and yaw 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 pitch motor and verify that the front propeller rotates.
2. Similarly, apply 4V to Analog Output Channel #1 to drive the yaw motor and verify that the rear 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 Section 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 Encoder Input Channel #0 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 downward, resting position to the horizontal is about 40 degrees. Thus it should read approximately 455 counts.
2. Similarly, measure the Encoder Input Channel #1. This encoder measures 8192 counts per full revolution. Rotate the helicopter body one full rotation and verify that 8192 is being measured.

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] Faulhaber. *Model 006C Motor Series 2842*, 2003.

[2] Pittman. *LO-COG DC Servo Motors 8000, 9000, 14000*, 2010.

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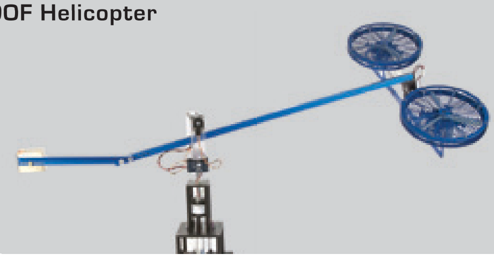
3 DOF Helicopter



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