

# CFR External Device Control Mode Protocol

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## Glossary

EDCM External Device Control Mode

ED External Device

CFR Concrete Finishing Robot

HMI Human Machine Interface

## 1 Overview

This document defines the command server protocol for the CFR Control Server. This is intended for an external device to assume control of the motors and thus motion of the CFR.

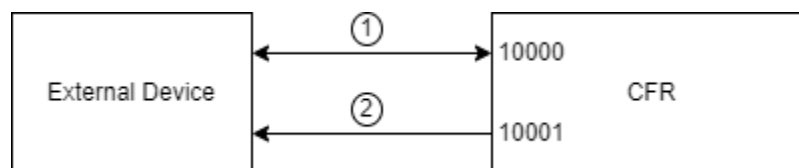


Figure 1: Overview of communication channels.

Figure 1 shows the communication architecture of the CFR Control Server. Channel (1) allows the external device to send commands and receive replies from the CFR. Channel (2) allows the CFR to feedback position of the CFR and of each motor on a regular interval.

The process states and possible transitions in the CFR is shown as a sequential function chart in Figure 2.

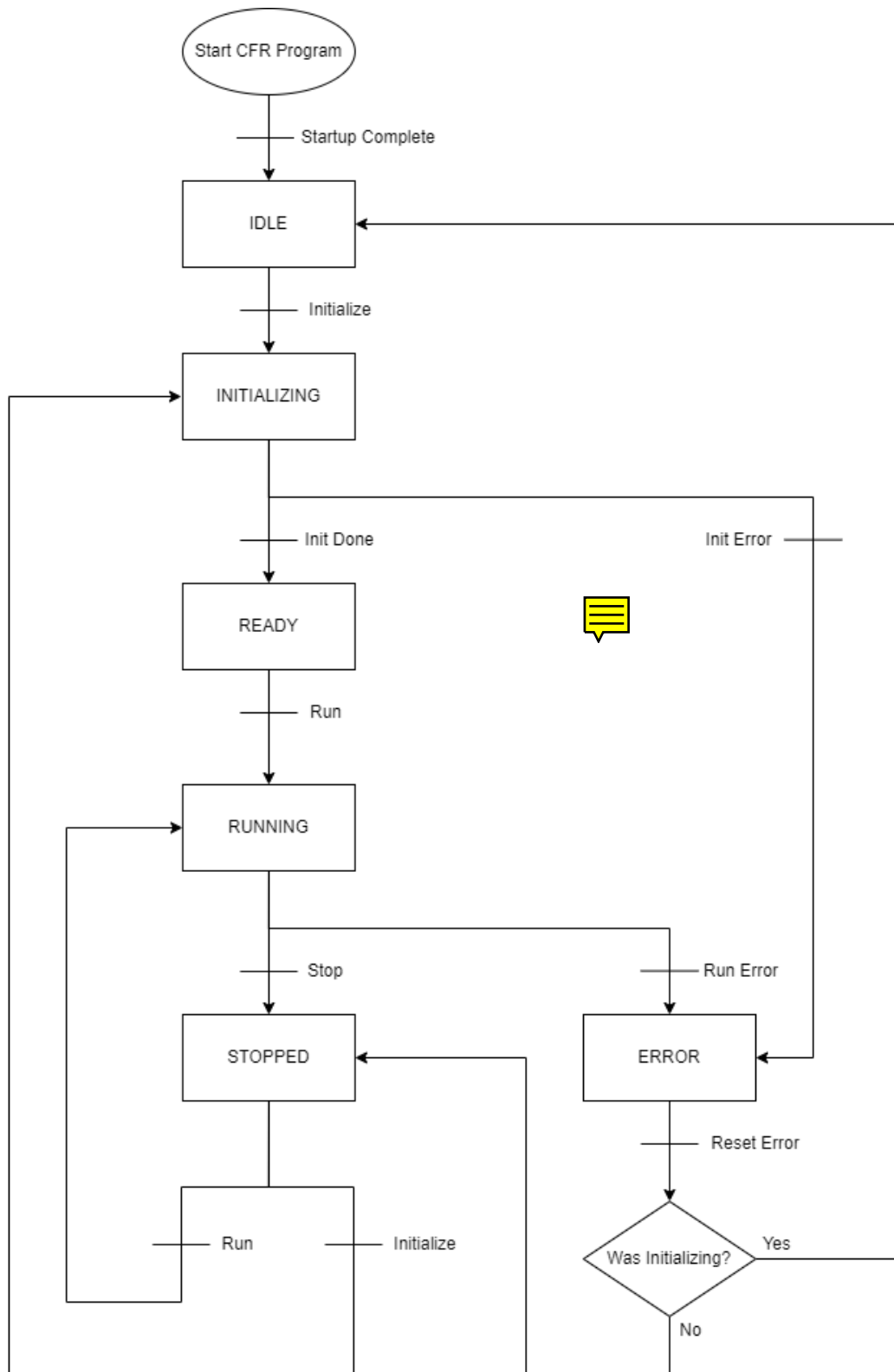


Figure 2: Process State Sequential Function Chart

To allow the CFR to receive and respond to commands from the external device, the user is required to toggle the button “External Device Control” on the CFR HMI, as shown in Figure 3.



Figure 3: External Device Control Mode switch on HMI

## 2 Protocol

The protocol shall consist of ASCII characters only and are case-insensitive. All messages are terminated with '\n' (linefeed character). Communication shall be through TCP packets. The CFR will listen for commands on port 10000 and reply on the same channel in a half-duplex manner. Feedback data is sent at regular intervals through port 10001. The feedback data stream at port 10001 is initiated by a command at port 10000.

In the sections below, ED refers to the external device and CFR the CFR command server. We shall refer the channel at port 10000 as channel 1, and at port 10001 as channel 2. The following sections describes the commands available for channel 1, except for section 2.13, which describes the feedback data stream format.

## 2.1 Query Process State

This message is used for querying the current process state of the CFR.

| Sender       | Message / Description  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
|--------------|--|------|--|--------------|----------------------|-------|-----------------------------------|---------|-----------------|---------|-----------------|-------|
| ED           | PSTATE   |      |  |              |                      |       |                                   |         |                 |         |                 |       |
|              | Query current process state of CFR.  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| CFR          | PSTATE, <state>  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
|              | <p>Reply with current CFR process state. See Figure 2 for an illustration of the transition between states.</p> <p>state is one of the following states:</p> <table><tr><td>IDLE</td><td>CFR is idle and not ready to accept commands from the external device.</td></tr><tr><td>INITIALIZING</td><td>CFR is initializing.</td></tr><tr><td>READY</td><td>CFR is ready to receive commands.</td></tr><tr><td>RUNNING</td><td>CFR is running.</td></tr><tr><td>STOPPED</td><td>CFR is stopped.</td></tr><tr><td>ERROR</td><td>CFR has encountered an error.</td></tr></table> | IDLE | CFR is idle and not ready to accept commands from the external device. | INITIALIZING | CFR is initializing. | READY | CFR is ready to receive commands. | RUNNING | CFR is running. | STOPPED | CFR is stopped. | ERROR |
| IDLE         | CFR is idle and not ready to accept commands from the external device.   |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| INITIALIZING | CFR is initializing.   |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| READY        | CFR is ready to receive commands.  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| RUNNING      | CFR is running.  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| STOPPED      | CFR is stopped.  |      |  |              |                      |       |                                   |         |                 |         |                 |       |
| ERROR        | CFR has encountered an error.  |      |  |              |                      |       |                                   |         |                 |         |                 |       |

### Sample

ED: PSTATE

CFR: PSTATE, READY

## 2.2 Query Run Mode

This message is used for querying the current run mode of the CFR.

| Sender    | Message / Description  |         |   |         |  |           |  |          |  |          |
|-----------|--|---------|---|---------|--|-----------|--|----------|--|----------|
| ED        | MODE   |         |   |         |  |           |  |          |  |          |
|           | Query the current run mode of CFR.   |         |   |         |  |           |  |          |  |          |
| CFR       | MODE, <mode>   |         |   |         |  |           |  |          |  |          |
|           | <p>Reply with current CFR run mode.</p> <p>mode is one of the following:</p> <table><tr><td>MANUAL1</td><td>CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis controls each axis of the motor.</td></tr><tr><td>MANUAL2</td><td>CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis moves the CFR linearly.</td></tr><tr><td>SEMI-AUTO</td><td>CFR is in semi-automatic mode, where positioning is stabilized by the automatic program using the beacon position. Joystick is used to shift this stabilized position.</td></tr><tr><td>MPT-AUTO</td><td>CFR is in autonomous mode, controlled by the internal program.</td></tr><tr><td>NYP-AUTO</td><td>CFR is in autonomous mode, controlled from external device.</td></tr></table> | MANUAL1 | CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis controls each axis of the motor. | MANUAL2 | CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis moves the CFR linearly. | SEMI-AUTO | CFR is in semi-automatic mode, where positioning is stabilized by the automatic program using the beacon position. Joystick is used to shift this stabilized position. | MPT-AUTO | CFR is in autonomous mode, controlled by the internal program. | NYP-AUTO |
| MANUAL1   | CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis controls each axis of the motor.  |         |   |         |  |           |  |          |  |          |
| MANUAL2   | CFR is in manual mode, where the motion is entirely determined by joystick input. Each joystick axis moves the CFR linearly.   |         |   |         |  |           |  |          |  |          |
| SEMI-AUTO | CFR is in semi-automatic mode, where positioning is stabilized by the automatic program using the beacon position. Joystick is used to shift this stabilized position.   |         |   |         |  |           |  |          |  |          |
| MPT-AUTO  | CFR is in autonomous mode, controlled by the internal program.   |         |   |         |  |           |  |          |  |          |
| NYP-AUTO  | CFR is in autonomous mode, controlled from external device.  |         |   |         |  |           |  |          |  |          |

### Sample

ED: MODE

CFR: MODE, MANUAL2

## 2.3 Toggle NYP-AUTO Run Mode

This command is used to toggle the NYP-Auto mode (External Device Control Mode).

| Sender | Message / Description   |
|--------|---|
| ED     | <code>NYPAUTO, &lt;enb&gt;</code>   |
|        | <p>Toggle between control by CFR internal program and External Device Control Mode.</p> <p>Set <code>enb</code> to 1 to enable, and 0 to disable.</p> <p>Note that this mode can be enabled from any run mode. However, the user is advised to switch only from MANUAL1 or MANUAL2 mode. If this mode is disabled, the CFR run mode will revert back to whatever mode the joystick lever is in.</p> |
| CFR    | <code>NYPAUTO, OK, &lt;enb&gt;</code>   |
|        | Acknowledge command completed successfully.   |
| CFR    | <code>NYPAUTO, ERR, &lt;errmsg&gt;</code>   |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message.   |

Sample when command is successful

ED:        `NYPAUTO, 1`

CFR:       `NYPAUTO, OK, 1`

Sample when command is unsuccessful

ED:        `NYPAUTO, 1`

CFR:       `NYPAUTO, ERR, NOT_IN_MANUAL`

## 2.4 Start/Stop Feedback Data Stream

This is a command to run start or stop the feedback data stream.

| Sender | Message / Description   |
|--------|---|
| ED     | FB, <enb>   |
|        | Start/Stop the data stream at channel 2.<br>enb: 1 to start, 0 to stop                        |
| CFR    | FB, OK, <enb>   |
|        | Acknowledge command completed successfully. The data stream will start at channel 2.          |
| CFR    | FB, ERR, <errmsg>   |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message. |

Sample when command is successful

ED: FB, 1

CFR: FB, OK, 1

Sample when command is unsuccessful

ED: FB, 1

CFR: FB, ERR, CFR\_NOT\_READY



## 2.5 Initialize CFR

This is a command to initialize the CFR, to bring it from the IDLE / STOPPED state to the READY state.

| Sender | Message / Description  |
|--------|--|
| ED     | INIT   |
|        | Initialize the CFR. This is possible only when the CFR is in IDLE or STOPPED process state. See Figure 2 to see process state transition sequence. |
| CFR    | INIT,OK  |
|        | Replies when the CFR has started initialization process.   |
| CFR    | INIT,ERR,<errmsg>  |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message.  |

Sample when command is successful

```
ED:      INIT
CFR:     INIT,OK
```

Sample when command is unsuccessful

```
ED:      INIT
CFR:     INIT,ERR,INCORRECT_STATE
```

## 2.6 Start CFR Program

This command is used to start / resume the CFR program

| Sender | Message / Description   |
|--------|---|
| ED     | START   |
|        | Start the CFR program from READY process state, or resume from a STOPPED process state. See Figure 2 for the transition sequence. |
| CFR    | START, OK   |
|        | Replies when the CFR has accepted the start signal to transition to the RUNNING state.  |
| CFR    | START, ERR, <errmsg>  |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message.                                     |

Sample when command is successful

ED:        START

CFR:       START, OK

Sample when command is unsuccessful

ED:        START

CFR:       START, ERR, CFR\_NOT\_READY

## 2.7 Stop CFR Program

This is a command used to stop the CFR program.

| Sender | Message / Description   |
|--------|---|
| ED     | STOP  |
|        | Stops the CFR program. This will also cut the engine at the same time.                        |
| CFR    | STOP, OK  |
|        | Replies when the CFR has started the stop process.  |
| CFR    | STOP, ERR, <errmsg>   |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message. |

Sample when command is successful

```
ED:      STOP
CFR:     STOP, OK
```

Sample when command is unsuccessful

```
ED:      STOP
CFR:     STOP, ERR, PROGRAM_NOT_RUNNING
```

## 2.8 Start Engine

This is a command used to start the CFR engine.

| Sender | Message / Description  |
|--------|--|
| ED     | STARTENGINE  |
|        | Starts the CFR Engine. The engine can only be started when the CFR program is in RUNNING process state. Note that there is no sensor to check that the engine has started running. Visual observation is required. |
| CFR    | STARTENGINE, OK  |
|        | Replies when the CFR has started the engine start sequence   |
| CFR    | STARTENGINE, ERR, <errmsg>   |
|        | Reply message when command is not successful, where errmsg is the error message.   |

Sample when command is successful

ED:        STARTENGINE  
CFR:        STARTENGINE, OK

Sample when command is unsuccessful

ED:        STARTENGINE  
CFR:        STARTENGINE, ERR, PROGRAM\_NOT\_RUNNING

## 2.9 CFR Linear Motion

This is a command used to move the CFR in a linear motion.

| Sender | Message / Description   |
|--------|---|
| ED     | CTRL,<spd>,<fwd>,<rot>,<side>   |
|        | <p>Sends a control command containing the four parameters affecting the CFR motion, namely</p> <p>spd: blade speed, value between 0 and 150 in rpm,<br/>fwd: forward/backward, value between -1.0 and 1.0,<br/>rot: rotation, value between -1.0 and 1.0, and<br/>side: sideways motion, value between -1.0 and 1.0.</p> <p>The four parameters also represent the position of the joystick lever used to control the motion of the CFR. This is almost equivalent to controlling the CFR using MANUAL2 mode.</p> |
| CFR    | CTRL,OK   |
|        | Acknowledge command has completed successfully.   |
| CFR    | CTRL,ERR,<errmsg>   |
|        | Reply message when command is not successful, where errmsg is the error message.  |

Sample when command is successful

```
ED:      CTRL,100,0.5,0,0      # move forward at 50% value and
                                a blade speed of 100 rpm

CFR:     CTRL,OK
```

Sample when command is successful

```
ED:      CTRL,90,-0.5,0.2,0    # reverse at 50% value, rotate
                                at 20% value, with a blade
                                speed of 90 rpm

CFR:     CTRL,OK
```

Sample when command is unsuccessful

ED: CTRL,200,0.2,0.1,1  
CFR: CTRL,ERR,BLADE\_SPEED\_ERR

## 2.10 CFR Motion Using Motor Axis

This is a command used to move the CFR using individual motor axis.

| Sender | Message / Description   |
|--------|---|
| ED     | AXIS,<spd>,<LX>,<RX>,<RY>   |
|        | <p>Sends a control command setting the four axis positions affecting the CFR motion, namely</p> <p>spd: blade speed, value between 0 and 150 in rpm,<br/>LX: LX motor position, value between -1.0 and 1.0,<br/>RX: RX motor position, value between -1.0 and 1.0, and<br/>RY: RY motor position, value between -1.0 and 1.0.</p> <p>The four parameters also represent the position of the joystick lever used to control the each motor axis of the CFR. This is almost equivalent to controlling the CFR using MANUAL1 mode.</p> |
| CFR    | AXIS,OK   |
|        | Acknowledge command has completed successfully.   |
| CFR    | AXIS,ERR,<errmsg>   |
|        | Reply message when command is not successful, where errmsg is the error message.  |

Sample when command is successful

```
ED:    AXIS,100,0.5,0,0           # position LX motor to 50%
                                     value and a blade speed of 100
                                     rpm

CFR:    AXIS,OK
```

Sample when command is successful

```
ED:    AXIS,90,-0.5,0.2,0        # set LX motor at 50% value,
                                     and RX motor at 20% value, with
                                     a blade speed of 90 rpm

CFR:    AXIS,OK
```

### Sample when command is unsuccessful

ED:        AXIS,200,0.2,0.2,0.1

CFR:       AXIS,ERR,BLADE\_SPEED\_ERR



## 2.11 Set Blade Angle

This is a command used to set the blade angle of the CFR.

| Sender | Message / Description  |
|--------|--|
| ED     | <b>BLADEANG</b> , <angle>  |
|        | Sets the blade angle for the CFR, where <code>angle</code> is in degrees. The range of angle is between 0 and 15 inclusive. This command can be given when the CFR is in any process state. However, the blade angle will only take effect when the CFR transitions from READY to RUNNING state. |
| CFR    | BLADEANG, OK   |
|        | Acknowledge command has completed successfully.  |
| CFR    | BLADEANG, ERR, <errmsg>  |
|        | Reply message when command is not successful, where <code>errmsg</code> is the error message.  |

Sample when command is successful

```
ED:      BLADEANG, 10                # set blade angle to 10 deg
CFR:     BLADEANG, OK
```

Sample when command is unsuccessful

```
ED:      BLADEANG, 20                # set blade angle to 20 deg
CFR:     BLADEANG, OUT_OF_RANGE
```

## 2.12 Query Beacon Positions

This is a command used to query the stationary beacon positions.

| Sender | Message / Description  |
|--------|--|
| ED     | BEACONS  |
|        | Query the stationary beacon positions.   |
| CFR    | BEACONS, <bcnt>, <bnum1>, <x1>, <y1>, <bnum2>, <x2>, <y2>, ...   |
|        | <p>bcnt is the number of beacons in the map. Returns the beacon N positions in the following format:</p> <p>bnumN: beacon number for beacon N, which may not be in order<br/>xN: x-axis position of beacon N in metres,<br/>yN: y-axis position of beacon N in metres.</p> <p>The CFR will return N sets of the above records if there are N beacons in the map.</p> |

Sample when command is successful

ED: BEACONS

CFR: BEACONS, 4, 1, 0, 0, 2, 10, 0, 3, 10, 8, 4, 0, 8 # returns data for 4 beacons

ED: BEACONS

CFR: BEACONS, 0 # no beacons are detected

## 2.13 Feedback Data Stream

This is the data stream format sent to the external device on channel 2. This is initiated by the FB command in section 2.4.

| Sender | Message / Description   |
|--------|---|
| CFR    | <p>&lt;ts&gt;,&lt;x&gt;,&lt;y&gt;,&lt;theta&gt;,&lt;vx&gt;,&lt;vy&gt;,&lt;vtheta&gt;,&lt;bspd&gt;,&lt;bangle&gt;,&lt;lx&gt;,&lt;rx&gt;,&lt;ry&gt;,</p> <p>ts: timestamp in ms,<br/>x: distance in metres in the x-axis from origin,<br/>y: distance in metres in the y-axis from origin,<br/>theta: orientation of the CFR in degrees,<br/>bspd: current blade speed in rpm,<br/>bangle: current blade angle in degrees,<br/>vx: velocity in x-axis in m/s,<br/>vy: velocity in y-axis in m/s,<br/>vtheta: angular velocity of the CFR in deg/s.<br/>lx: current LX motor position in degrees,<br/>rx: current RX motor position in degrees,<br/>ry: current RY motor position in degrees</p> <p>The packets are sent at intervals of about 80ms.</p> |

Example data stream:

```
CFR: 100200,3.53,5.52,92.0,0.5,0.1,0.01,101,10,2.1,-10.2,4.2
CFR: 100280,3.55,5.61,91.2,0.55,0.11,0.02,100,10,2.2,-10.3,4.0
CFR: 100361,3.51,5.74,92.1,0.52,0.12,0.01,102,10,1.9,-9.9,3.5
```

### 3 Example Program

This is a sample program for controlling the CFR through an external device. The following represents a communication log over channel 1 (port 10000).

```
ED:    PSTATE                                # get process state
CFR:    PSTATE,IDLE
ED:    MODE                                  # get run mode
CFR:    MODE,MANUAL2
ED:    BEACONS                               # get beacon positions
CFR:    BEACONS,4,1,0,0,2,10,0,3,10,8,4,0,8
ED:    NYPAUTO,1                             # set NYP autonomous mode
CFR:    NYPAUTO,OK
ED:    MODE                                  # check if run mode has
                                           transitioned
CFR:    MODE,NYP-AUTO
ED:    INIT                                  # start initialization
CFR:    INIT,OK
ED:    PSTATE                               # wait till process state
                                           is ready
CFR:    PSTATE,INITIALIZING
ED:    PSTATE
CFR:    PSTATE,READY
ED:    BLADEANG,10                          # set blade angle to 10
                                           deg
CFR:    BLADEANG,OK
ED:    FB,1
CFR:    FB,OK
ED:    START                                # start program
CFR:    START,OK
ED:    PSTATE                               # check if it is running
CFR:    PSTATE,RUNNING
ED:    CTRL,0,0,0,0                         # start sending commands
CFR:    CTRL,OK
ED:    STARTENGINE                          # start engine
CFR:    STARTENGINE,OK
ED:    CTRL,0,0,0,0                         # wait for engine to start
```

```

CFR:  CTRL,OK
ED:    CTRL,90,0,0,0          # ramp up blade speed
CFR:  CTRL,OK
ED:    CTRL,90,0.5,0,0        # move forward at 50%
CFR:  CTRL,OK
ED:    CTRL,90,0.5,0,0        # move forward at 50%
CFR:  CTRL,OK

ED:    STOP                  # Stop CFR. Engine will be
                             cut.

CFR:  STOP,OK
ED:    PSTATE                # check if it has stopped
CFR:  PSTATE,STOPPED

```

## 4 Safety

In order to maintain safe operation of the CFR, the following conditions will result in an **engine cut** when the CFR program is in NYP-AUTO mode and RUNNING process state:

1. When there is no CTRL command for more than 500ms.
2. When any of the channels at port 10000 or 10001 is dropped, or has error.

\*\*\* END OF DOCUMENT \*\*\*