Communications for the Piccolo avionics

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1 Introduction

Piccolo is a avionics system for flying small autonomous UAVs. This document describes the communications protocol used to talk to Piccolo avionics and ground station. Since the avionics is capable of autonomous operation multiple aircraft may be flown by a single operator. In order to facilitate this type of operation the datalink system used for Piccolo emphasizes the ability to communicate to multiple avionics from a single ground station. Therefore a communications facility is required which is able to multiplex individual streams of information from multiple avionics onto a wireless link.

1.1 Addressing

Each avionics is identified by an address, which is the same as the avionics serial number. A communications packet always includes a source and a destination address. Ground stations always use address 0 and operator interface PC's always use address 0xFFFE. Packets destined for all avionics use address 0xFFFF.

1.2 Streams

The data sent to or from any one avionics are made up of multiple bi-directional *streams* which are multiplexed onto the wireless channel. Each stream represents an endpoint in the avionics, which is either defined by software or by a physical port on the avionics.

1.3 Wireless link

Piccolo includes a built in wireless link made from the MHX-910/2400 frequency hopping radio from Microhard Systems Inc. The MHX radio is a 900Mhz or 2.4 GHz ISM band radio with good receive sensitivity and a maximum 1 Watt output power. The wireless link formed between radios extends from all the avionics to the ground station. Traditional wireless links were made of a single frequency, and multiple networks could be constructed by using multiple frequencies. With a frequency hopping radio the concept of networks defined by frequencies is replaced with networks defined by hopping patterns. Hence it is possible to have a network of radios using one hopping pattern while another network of nearby radios uses a separate hopping pattern. In each case a single ground station coordinates the communications for each network.

Piccolo also includes an external serial port which can be used for communications, either simultaneously with the built in link, or standalone. Running both links simultaneously is referred to as "multi-homed" operation.

1.4 Flow control

To support multiple aircraft the ground station manages flow control of the built-in network. Flow control refers to preventing multiple radios from transmitting at the same time. This is done by allowing one node of the network to dictate when every other node can talk, and for how long. Piccolo's way of doing this is with a polled system in which the ground station polls each avionics in "round-robin" fashion. Flow control can be selectively enabled on the external communications port.

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2 Stream implementation

The implementation of the stream multiplex/demultiplex logic is based upon a packet protocol running on a bi-directional link. Each packet sent over the link contains data for one stream. Figure 1 shows the different communications streams which must be multiplexed.

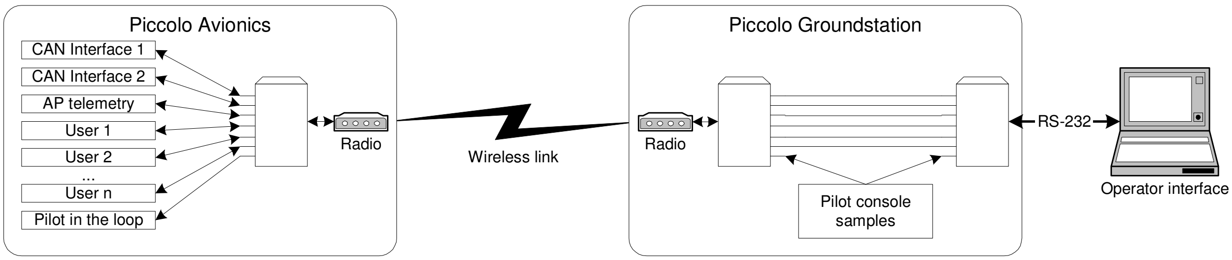

Figure 1. Piccolo communications facilities

Each stream is characterized by a physical port or a software defined endpoint. The endpoints are:

Table 1. Streams endpoints

Endpoint	Identifier	Value	Meaning
Network control	POLLING_STREAM	0	This stream is used for the polling and frame termination packets.
Differential Corrections	DGPS_STREAM	1	This stream carries differential corrections packets from the ground station to all avionics.
Pilot in the loop	PILOT_STREAM	2	The Piccolo ground station automatically samples the pilot console (if present) and injects the data into the wireless link at the start of each frame. The Piccolo avionics uses this data to provide pilot-in-the-loop operation, where the autopilot is suspended in favor of manually piloted operation. This endpoint is receive only.
Autopilot	AUTOPILOT_STREAM	3	This endpoint defines the primary command and control interface to the Piccolo avionics. In addition sensor and autopilot state information are sent from this endpoint.
Met system	MET_STREAM	4	This endpoint is used for meterological sensor sampling.
Gimbal	GIMBAL_STREAM	5	This endpoint is used to talk to a camera gimbal connected to the autopilot.
Payload	PAYLOAD_STREAM	6	Data to and from the payload serial port.
Payload 2	PAYLOAD2_STREAM	7	Data to and from the second payload serial port.
Debug	DEBUG_STREAM	8	Data used autopilot development work.

2.1 Stream packet protocol

The definition of the stream packet is given in Table 2. *Note:* it is important to understand that the packet defined in Table 2 is just a transport mechanism for stream data. Each stream is obligated to define its own stream-specific data contained in the payload of the general stream packet.

Table 2. General stream packet definition

<table>
<tr><th>Byte</th><th>Name</th><th colspan="2">Meaning</th></tr>
<tr><td>0</td><td>SYNC</td><td colspan="2">Synchronization character used to signal the receiving state machine that a stream packet may be forthcoming. Must be 0x5A.</td></tr>
<tr><td>1</td><td>SYNC1</td><td colspan="2">Second synchronization character used to signal the receiving state machine that a stream packet may be forthcoming. Must be 0xA5.</td></tr>
<tr><td>2</td><td>DestHi</td><td colspan="2" rowspan="2">Most and least significant byte of the destination address for this packet.</td></tr>
<tr><td>3</td><td>DestLo</td></tr>
<tr><td>4</td><td>SourceHi</td><td colspan="2" rowspan="2">Most and least significant byte of the source address of this packet.</td></tr>
<tr><td>5</td><td>SourceLo</td></tr>
<tr><td>6</td><td>SequenceHi</td><td colspan="2" rowspan="2">Most and least significant bytes of the sequence number for this stream. The sequence number is the sum of the last sequence and the amount of data in this packet.</td></tr>
<tr><td>7</td><td>SequenceLo</td></tr>
<tr><td>8</td><td>AckHi</td><td colspan="2" rowspan="2">Most and least significant bytes of the acknowledge number for this stream. The acknowledge number is the highest validated Sequence number for this stream.</td></tr>
<tr><td>9</td><td>AckLo</td></tr>
<tr><td>10</td><td>Stream</td><td colspan="2">Stream/endpoint identifier. This value indicates which stream's data is contained in this packet; see Table 1.</td></tr>
<tr><td rowspan="5">11</td><td rowspan="5">Flags</td><td>Bit</td><td>Meaning</td></tr>
<tr><td>0 (MSB)</td><td>POLLING_REQUEST bit for flow control.</td></tr>
<tr><td>1</td><td>FRAME_TERMINATION bit for flow control.</td></tr>
<tr><td>2-4</td><td>Reserved, set to zero</td></tr>
<tr><td>5-7</td><td>Packet link check</td></tr>
<tr><td>12</td><td>Size</td><td colspan="2">The number of data bytes in the packet.</td></tr>
<tr><td>13</td><td>HeaderCheck</td><td colspan="2">8 bit XOR checksum of bytes 0…12. This checksum allows the receiving state machine to determine if this header is valid. This provides rapid detection of bad SYNC characters.</td></tr>
<tr><td>14…Size+13</td><td>Data</td><td colspan="2">Size data bytes</td></tr>
<tr><td>Size+14</td><td>CRCHi</td><td colspan="2" rowspan="2">Most and Least significant byte of the cyclic redundancy check. The CRC applies to bytes 0…Size+13.</td></tr>
<tr><td>Size+15</td><td>CRCLo</td></tr>
</table>

Note that all multi-byte values are always sent with the most significant byte first, i.e. in Big-Endian order. This is true for all the packets used by Piccolo.

2.2 Avionics stream management

The multiplexing, de-multiplexing, and packet protocol are controlled by the stream manager onboard the avionics.

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2.2.1 Incoming streams

The receive stream manager pulls incoming packets off the link buffer and stuffs the packet payloads into the appropriate stream buffer, if the packet was addressed to the avionics. Individual streams are responsible for pulling the data from the stream buffer and sending it to the appropriate software service routine, or hardware port. The stream manager also watches for polling packets from the network control stream and singles the transmit stream manager when one is received.

2.2.2 Outgoing streams

The transmit stream manager multiplexes outgoing streams onto the bi-directional link in order of priority. Each time it is invoked the transmit stream manager fills the available space in the outgoing link buffer with packets constructed from the outgoing stream buffers. These stream buffers are examined in a specific order, first the autopilot buffer, then the CAN buffers, and finally any user defined buffers. The last thing the transmit stream manager does is send the frame termination packet on the network control stream. In this way the high priority streams get first shot at the available outgoing bandwidth on the link.

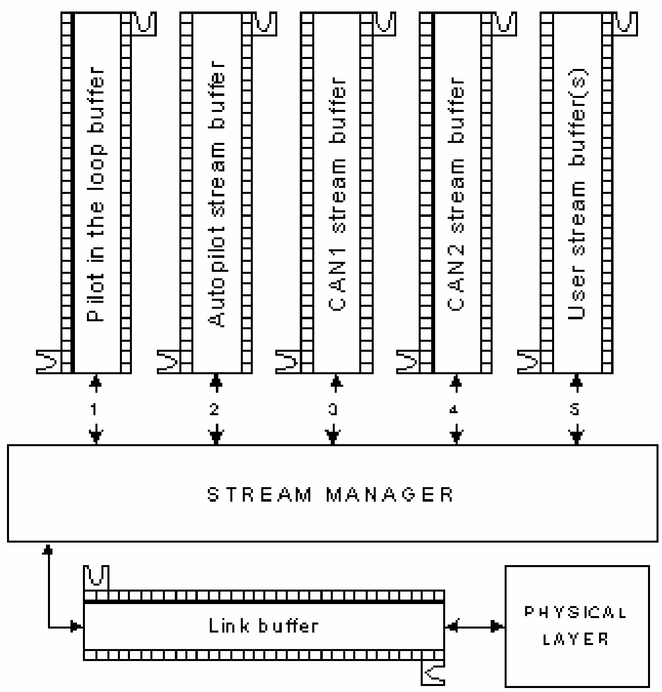

Figure 2. Stream manager

2.3 Ground station stream management

Unlike the avionics and operator interface the Piccolo ground station has several separate links over which it must multiplex stream data: the wireless link to one or more Piccolo avionics, and two serial links to the operator interface(s).

2.3.1 Operator interface

The ground station pulls stream packets off of the operator interface link and examines the address of the packet. If the packet is destined for address zero then it is for the ground station and is processed locally. If the address is nonzero the ground station places the packet in a first-in-first-out queue for the addressed avionics.

2.3.2 Avionics interface

The avionics interface contains all the logic to run the polling scheme outlined in 1.4. In addition it determines the frame time used for each polling cycle by examining the pilot commands received from the pilot console. When manual pilot control is selected the frame time decreases to a maximum of 80ms, otherwise the frame time is 230ms. In either case, if pilot in the loop commands are available the ground station sends them out as the first packet of each frame. If multiple aircraft are in the network then the avionics polls different addresses each frame, however the pilot command packet always contains the same address, the one specified by the operator interface for pilot in the loop commands. If no such specification has been received then the ground station does not send pilot in the loop commands.

After sending the pilot command, the ground station broadcasts differential corrections, if available, to all avionics. Then the ground station sends any data from the operator interface which was destined for the avionics addressed in that frame, up to the maximum amount of data allotted in that frame. Finally the ground station sends the polling packet with whatever data space remains in the frame. Any reply from the aircraft (except the frame terminator) is forwarded to the operator interface.

2.4 Flow control implementation

2.4.1 Process

The flow control implementation is used for the built-in MHX radio system, and optionally for external radio systems. The scheme is based upon logic in the ground station which knows the network address of all the avionics that the user wishes to communicate with. The ground station initiates each communication frame by sending a message addressed to the avionics of interest which indicates how long that avionics is allowed to talk. The steps are as follows:

Table 3. Flow control process

Step	Function
1	The ground station starts a communications frame and sends any uplink data to the avionics. The last packet of uplink data includes extra data that tells the avionics to transmit following receipt of the packet.
2	The avionics receives the polling packet and sends any waiting data out the serial port to the radio. The amount of data sent is less than or equal to the amount requested in the polling packet from the ground station. That last packet sent down includes a frame termination flag in the packet header which indicates to the ground station that it is done transmitting.

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3	The ground station receives the data from the avionics and forwards it to the operator interface or local hardware destination. In addition it watches for the frame termination flag. When it arrives the ground station assumes that the avionics is finished transmitting, and returns to step 1 with a new avionics address. It is possible that some packets of data will be lost, including the polling packet or the frame termination packet. To recover from this the ground station estimates how much time is required for the avionics to send all the data the ground station has allowed. If that amount of time elapses before the terminating packet is received the ground station returns to step 1 with a new avionics address.

2.4.2 Polling details

There are two methods to poll an avionics for a response. The first method is to send a stream packet with the `POLLING_STREAM` identifier and two bytes of data. The two bytes give the 16-bit unsigned number of bytes that the avionics is allowed to reply with, including the frame termination packet. This method is expensive since it incurs the overhead of a entire packet; and is therefore only used when there are no other packets going up to the avionics.

The second method piggybacks on an existing uplink packet. The ground station sets the `POLLING_REQUEST` bit in the flags field of the packet header. It then appends two bytes to the data section of the packet. The two bytes give the 16-bit unsigned number of bytes that the avionics is allowed to reply with.

2.4.3 Frame termination details

There are two methods for the avionics to terminate the communications frame. The first method is to send a zero length stream packet with the `POLLING_STREAM` identifier. This method is expensive since it incurs the overhead of a entire packet; and is therefore only used when there are no other packets going down to the groundstation. The second method piggybacks on an existing downlink packet. In this case the avionics sets the `FRAME_TERMINATION` bit in the flags field of the packet header.

2.4.4 Flow control timing

The amount of data that can be sent during a frame is a function of the radio specifics and is determined experimentally for each radio type. Generally the ground station supports two types of frames, slow and fast. Fast frames are designed to support high frequency, low latency applications like pilot in the loop commands. Slow frames sacrifice latency in order to move data more efficiently.

2.5 Guaranteed data delivery

The ground station and avionics work together to guarantee the delivery of data for some streams (autopilot and payload). The delivery guarantee works by using the sequence and acknowledge numbers in each packet. We define local and remote to designate if the sequence and acknowledge numbers were generated locally, or if they came from a packet (remote).

2.5.1 Sequence number

The sequence number is a stream specific 16-bit counter that tracks the amount of data sent to a stream. The receiver tracks the remote sequence number and validates it by computing a comparison sequence that is made from the current packet size and the last sequence number. If the comparison isn't correct then the receiver knows that data is missing or duplicated. For example:

- If the received sequence number is less than the previously received sequence number the data are considered old and the receiving stream discards the newly received data. The lost data flag is unchanged.
- If the received sequence number is greater than the previously received sequence number, but less than the computed sequence number, then some of the data is duplicated, and some of it is new. The receiving stream will append only the new data onto its existing buffer. The lost data flag is cleared.
- If the received sequence number is greater than the computed sequence number then data are missing. In this case the receiving stream discards the newly received data. The lost data flag is set.
- If the comparison is exactly correct then the receiving stream appends all of the new data on its receive buffer. The lost data flag is cleared.

Note that since the sequence number is only 16 bits it will wrap after 64Kbytes of data have been sent. Hence when one sequence number is compared to another the wrap must be accounted for. For example if the received sequence number is 0x0010 and the computed sequence number 0xFFF0 then the received sequence number is greater than the computed number by 0x0020.

2.5.2 Acknowledge number

Each time newly received data is validated the receiver updates the remote sequence number. This "remote sequence number" is actually the local acknowledge number. Hence sender's know that their data have been received by looking at the remote acknowledge number and seeing it increase to match the local sequence number that was last sent. The difference between the local sequence number and remote acknowledge number is the amount of data that has been sent but not acknowledged.

2.5.3 Lost data

If the receiver determines that data are lost then its next packet will include the lost data flag. The flag tells the remote side to re-wind its stream transmit buffer. The buffer will be reversed until the local sequence number matches the remote acknowledge number. Transmission then continues normally.

2.5.4 Re-synchronization

If the buffer cannot be re-wound far enough, or if communications have not yet been initialized, then the re-synchronization flag is set. When the receiver receives a packet with the re-sync flag set it sets its acknowledge number to match the sequence number in the packet. This is the recovery mechanism for cases where more data has been lost than the system can retransmit.

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2.5.5 Acknowledgement timeout

The mechanism given above will function as long as there is always data to move. However if all the data has been sent it is possible that the receiver will not realize that it has missed the last packet. In that case the sender must trigger the receiver to acknowledge its data. Hence the sender must keep an acknowledge timer which is used to send a zero length packet in the case of unacknowledged data. When the receiver gets the packet it will re-check its remote sequence number and determine that data are lost, replying with the appropriate data lost flag.

For cases where the receiver is gone (lost communications) the acknowledgement timer is only allowed to elapse a fixed number of times. After the last elapse the remote acknowledge number is updated and the re-sync flag is set.

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3 Ground station communications

Communications destined for the ground station use destination address 0. There is only one software endpoint in the groundstation, and hence only one stream, GS_STREAM (3). The operator interface is the only device that actually sends data destined for the ground station. All ground station stream packets follow the format in Table 4.

Table 4. General ground station stream packet format

Byte	Name	Meaning
0	SYNC	Synchronization character used to signal the receiving pilot stream that a packet *may* be forthcoming. Must be 0xA0.
1	SYNC1	Second synchronization character used to signal the receiving pilot stream that a packet *may* be forthcoming. Must be 0x05
2	PacketType	Command and control packet type, see Table 18.
3	Size	The number of payload bytes in the pilot packet.
4…Size+3	Payload	Size payload bytes
Size+4	CRCHi	Most and Least significant byte of the cyclic redundancy check, respectively. The CRC applies to bytes 0…Size+3.
Size+5	CRCLo	

3.1 Ground station packets

Table 5 gives the different packet types that the GS_STREAM of the ground station understands.

Table 5. Ground station packet definition

Name	#	Dir	Period	Meaning
ADD_ADDRESS	0	Both	N/A	This packet contains the address of an avionics that the ground station should initiate communications with.
DEL_ADDRESS	1	Both	N/A	This packet contains the address of an avionics that the ground station should terminate communications with.
PILOT_ADDRESS	2	Both	N/A	This packet contains the address of an avionics to which pilot commands should be sent.
DGPS_POSITION	3	Both	5	This packet contains base position data which is used to generate broadcast differential corrections.
GS_VERSION	4	Both	N/A	This packet is used for the version information of the firmware in the ground station.
REQUEST_CONFIG	5	Up	N/A	This packet is used to request the current network configuration from the ground station.
GS_TELEMETRY	7	Down	2	This packet is used for system telemetry from the ground station.
GROUP_ADDRESS	8	Down	5	This packet gives the entire network list used by the ground station.
GS_RADIO_SETTINGS	9	Both	N/A	This packet gives is used to read or

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				change the radio settings.
GS_SPECTRUM	10	Down	N/A	This packet is used to invoke the spectrum analyzer function of the MHX radio, and return the results
DYNAMIC_ENUMERATION	11	Both	N/A	This packet is used to enable or disable the dynamic network enumeration feature of the ground station.
GS_SPECTRUM2	12	Both	N/A	This packet is used to invoke the spectrum analyzer feature of the MHX420 radio, and return the results.

3.1.1 Packets sent periodically

3.1.1.1 Group Address

This packet contains the entire network configuration of the ground station. It is sent automatically every 5 seconds. The packet is variable length, depending on the number of addresses in the ground station polling list. Up to 80 different addresses can be listed.

Table 6. Add address data.

Byte	Name	Meaning	
0	NumAddresses	8-bit unsigned number of addresses in the polling list.	
1	PilotIndex	8-bit unsigned index of the pilot address. The index refers to the location in the following list which contains the pilot address. If there is no pilot address this value will be 255.	
2	Flags_0	Bit	Meaning
3	Flags_1	0(MSB)	Set if BAI ground station hardware.
		1	Reserved.
		2	Set if TS-4000 ground station hardware.
		3	Set if external datalink (else MHX).
		4	Reserved.
		5	Reserved.
		6	Reserved.
		7	Set if dynamic enumeration is enabled.
		8 (MSB)	MHX radio type. The type is an enumeration in the following order: MHX 910, MHX2400, MHX 920, MHX 2420, MHX 420, MHX 320, MHX 1320.
		9	
		10	
		11	
		12	Reserved.
		13	Reserved.
		14	Reserved.
		15 (LSB)	Set if ack ratio data is not included.
4	AddressHi_0	First 16-bit network address in the polling list.	
5	AddressLo_0		
	…		
N*2+4	AddressHi_N	Nth 16-bit network address in the polling list. The packet can encode up to 80 different addresses.	
N*2+5	AddressLo_N		
	…		

N*3+6	AckRatio	8-bit unsigned acknowledgement ratio in percent for the Nth address in the polling list. The acknowledgement ratio is the ratio of acknowledged communications frames to polled communications frames. It is a measure of the communications link performance to this avionics. 100 is best and 0 is worst.

3.1.1.2 GS Telemetry

This packet is sent every two seconds and contains telemetry information for the groundstation.

Table 7. Ground station telemetry

Byte	Name	Meaning
0	LAT_0	32-bit signed integer latitude, in milli-arcseconds.
1	LAT_1	
2	LAT_2	
3	LAT_3	
4	LON_0	32-bit signed integer longitude, in milli-arcseconds.
5	LON_1	
6	LON_2	
7	LON_3	
8	Height_0	32-bit signed integer GPS height, in centimeters above sea level.
9	Height_1	
10	Height_2	
11	Height_3	
12	VNorth_0	16-bit signed integer North component of the groundspeed, in centimeters per second.
13	VNorth_1	
14	VEast_0	16-bit signed integer East component of the groundspeed, in centimeters per second.
15	VEast_1	
16	NumSats	The number of satellites tracked by the GPS.
17	NumVis	The number of visible satellites.
18	DOP_0	16-bit unsigned dilution-of-precision of the GPS solution, in units of 0.1 DOP.
19	DOP_1	
20	STATUS_0	16-bit GPS status word.

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21	STATUS_1	• Bit 0-2 (msb): 111 = 3D Fix 110 = 2D Fix 101 = Propagate Mode 100 = Position Hold 011 = Acquiring Satellites 010 = Bad Geometry 001 = Reserved 000 = Reserved • Bit 3: Set if dead-reckoned • Bit 4: Set if satellite based augmentation system • Bit 5: Reserved • Bit 6: Fast acquisition position • Bit 7: GPS data are raw (unfiltered) • Bit 8: GPS is performing cold start • Bit 9: GPS is differentially corrected • Bit 10: Position lock mode enabled • Bit 11: Auto survey mode • Bit 12: Insufficient satellites visible • Bit 13-14: 11 = No antenna power 10 = Antenna undercurrent 01 = Antenna overcurrent 00 = Antenna good • Bit 15: Reserved
22	Year_0	16-bit unsigned GPS year.
23	Year_1	
24	Month	GPS month, 1…12
25	Day	GPS day, 1…31
26	Hour	GPS hour, 0…23
27	Minute	GPS minutes, 0…59
28	Second	GPS seconds, 0…59
29	Reserved	GPS fractional seconds in units of 1/100ths of a second. The GPS time represents the time of the data in this packet, not necessarily the time of the last GPS report.
30	RSSI	Receive signal strength indicator for the datalink, as a signed 8 bit number in dBm, typically from -71 to -115.
31	Vin_0	16-bit unsigned input voltage in milli-Volts
32	Vin_1	
33	Iin_0	16-bit unsigned input current in milli-Amps
34	Iin_1	
35	5.3_0	16-bit unsigned first stage (5.3) voltage in milli-Volts
36	5.3_1	
37	5D_0	16-bit unsigned five volt digital rail voltage in milli-Volts
38	5D_1	
39	5A_0	16-bit unsigned five volt analog rail voltage in milli_Volts
40	5A_1	
41	CPUV_0	16-bit unsigned 3.3 volt main processor voltage in milli_Volts
42	CPUV_1	
43	GPSV_0	16-bit unsigned 3.0 volt GPS input voltage in milli_Volts
44	GPSV_1	
45	BoardT_0	Piccolo board temperature as a unsigned 16 bit number in hundredths of Kelvins.
46	BoardT_1	
47	VSWR_0	16-bit unsigned MHX datalink VSWR measurement in 1000ths. Less than 1000 if measurement unavailable.
48	VSWR_1	

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49		
50	Pressure_0	Unsigned 32-bit static pressure in Pascals. Not all groundstations have a pressure sensor. This value will be zero if the sensor does not exist.
51	Pressure_1	
52	Pressure_2	
53	Pressure_3	

3.1.2 Command packets

3.1.2.1 Radio settings packet

The radio settings packet is used to request or change the radio settings. Send the packet with zero length to request the current settings. Note that when requesting or changing the radio settings the radio must be taken off line, which will result in a temporary loss of communications. Hence this should not be done during manual control.

Table 8. Radio settings packet

Byte	Name	Meaning
0	Channel	The hopping pattern to use with the MHX radio. Valid settings are 0 to 57. This field is ignored for the MHX420 or non-microhard radios
1	Power	8-bit unsigned power setting to use with the MHX radio. Units are in 10s of milliwatts.
2	Speed	Radio speed setting. Use zero for default speed, 1 for narrow band operation, and 3 for wide band operation. This setting only applies to MHX_x20 radios with dual receiver front end.
3	Radio Type	The type of internal radio. This value is only for downlink packets Defined types are: 0) MHX_910. 900MHz ISM microhard radio. 1) MHX_2400. 2.4GHz ISM microhard radio. 2) MHX_920. Next generation 900MHZ ISM microhard radio. 3) MHX_2420. Next generation 2.4GHz ISM microhard radio. 4) MHX_420. 450 MHz coherent frequency microhard radio. 5) MHX_320. 350 MHz coherent frequency microahrd radio. 6) MHX_1320. 1.3 GHz coherent frequency microhard radio. 7) EXTEND_900 900MHz ISM Maxstream radio.
4	Freq_0	32-bit single precision floating point radio frequency in megahertz
5	Freq_1	
6	Freq_2	
7	Freq_3	

3.1.2.2 Spectrum analyzer

This packet contains the results of the spectrum analyzer function on the microhard radio. The analyzer function scans through all the channels on the radio and reports the average and maximum signal strength on each channel. This packet is sent in response to a GS_SPECTRUM packet of zero length. If the radio installed is an MHX-420 then the spectrum analyzer function will respond with GS_SPECTRUM2 and will use the default settings of 250ms dwell time, 50kHz spacing, with the frequency centered on the current frequency. The number of channels encoded can vary from 2 to 127 and should be determined based upon the packet length

Table 9. Spectrum analyzer packet

Byte	Name	Meaning

0	Chan1Avg	Signed average signal level on channel 1 in dBm.
1	Chan1Max	Signed max signal level on channel 1 in dBm.
2	Chan2Avg	Signed average signal level on channel 2 in dBm.
3	Chan2Max	Signed max signal level on channel 2 in dBm.
4-251	…	Channels 3 through 126
252	Chan127Avg	Signed average signal level on channel 127 in dBm.
253	Chan127Max	Signed max signal level on channel 127 in dBm.
254	Reserved	Reserved

3.1.2.3 Spectrum analyzer 2

This packet contains the results of the spectrum analyzer function on the microhard MHX-420 radio. This spectrum function is different than GS_SPECTRUM in that it does not include the peak power measurement and specifies the exact frequency and dwell time of each measurement. The packet contains up to 246 measurements. To request a spectrum sweep send this packet with the first eight bytes filled out to request the type of data needed. If this packet is sent to a groundstation equipped with a MHX radio that is not a MHX-420 then the spectrum operation will be performed according to the built-in analysis. Such a system will respond with the GS_SPECTRUM packet.

Table 10. Spectrum analyzer packet

Byte	Name	Meaning
0	Freq_0	32-bit single precision floating point radio frequency in megahertz at which the spectrum sweep starts.
1	Freq_1	
2	Freq_2	
3	Freq_3	
4	Spacing_0	16-bit unsigned measurement spacing in 100Hz increments. For example 1 indicates take a measurement every 100Hz. 10,000 takes a measurement every 1MHz.
5	Spacing_1	
6	Dwell	8-bit unsigned measurement dwell time in tens of milliseconds. Longer dwell times give more accurate results but take longer to perform.
7	Number	8-bit unsigned number of measurements in the packet.
8	Signal-0	Unsigned 8 bit signal strength in dBm at the frequency specified in bytes 0-3. The signal is reported as positive but should be inverted such that the measurement goes from -255 to 0.
9…8+Number	Signal-n	Unsigned 8-bit signal strength in dBm at Freq + n*Spacing. (n is byte number minus 8) The signal is reported as positive but should be inverted such that the measurement goes from -255 to 0.

3.1.2.4 GS Version

This packet returns system version information. The ground station sends this packet whenever it receives a zero-length GS version packet.

Table 11. Ground station version packet

Byte	Name	Meaning

0	Major	Major software version number.
1	Minor	Minor software version number.
2	Sub	Sub software version number.
3	Released	Non-zero if software is released, else software is test version
4	SoftYear_0	16-bit unsigned year of the software release
5	SoftYear_1	
6	SoftMonth	Month of the software release, 1-12
7	SoftDay	Day of the software release, 1-31
8	BoardSN_0	Unsigned 32-bit board serial number.
9	BoardSN_1	
10	BoardSN_2	
11	BoardSN_3	
12	BoardRev_0	Unsigned 32-bit board revision number.
13	BoardRev_1	
14	BoardRev_2	
15	BoardRev_3	
16	BoardConfig_0	Unsigned 32-bit board configuration code.
17	BoardConfig_1	
18	BoardConfig_2	
19	BoardConfig_3	
20	BoardYear_0	16-bit unsigned year of the board fabrication
21	BoardYear_1	
22	BoardMonth	Month of the board fabrication, 1-12
23	BoardDay	Day of the board fabrication, 1-31

3.1.2.5 Request configuration

This is a zero length packet which is used to request the current configuration setup of the groundstation. The groundstation will reply with a `GROUP_ADDRESS` packets, as well as a `DGPS_CONFIGURATION` packet.

3.1.3 System setup packets

3.1.3.1 Add Address

This packet contains the address of an avionics that the ground station should initiate communications with. The ground station will allocate the necessary network data structures and add this address to the list of avionics to be polled, unless it is already on the list. The ground station echoes the received packet back to the operator interface.

Table 12. Add address data.

Byte	Name	Meaning
0	AddressHi	16-bit network address of an avionics to poll.
1	AddressLo	

3.1.3.2 Del Address

This packet contains the address of an avionics that the ground station should terminate communications with. If the passed address is not the pilot address the ground station will de-allocate the necessary network data structures and remove this address to the list of aircraft to be polled. If the passed address is zero then the ground station will terminate communications with

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all of the avionics in its polling list, excepting the pilot address. For each avionics address which is removed the ground station will send a `DEL_ADDRESS` packet back to the operator interface.

Table 13. Delete address data.

Byte	Name	Meaning
0	AddressHi	16-bit network address of an avionics to stop polling.
1	AddressLo	

3.1.3.3 Pilot Address

This packet contains the address of an avionics that the ground station should send pilot in the loop commands too. If this address is not already listed in the ground station it will allocate the necessary network data structures and add this address to the list of aircraft to be polled. The ground station echoes the received packet back to the operator interface.

Table 14. Pilot address data.

Byte	Name	Meaning
0	AddressHi	16-bit network address of the avionics to receive the pilot commands.
1	AddressLo	

3.1.3.4 Differential corrections

The differential corrections packet includes data which is used to configure the ground station base station setup. The ground station uses this packet to configure its base station GPS receiver and then broadcasts the DGPS corrections to all avionics. The ground station echoes the received packet back to the operator interface.

Table 15. Differential corrections setup data

Byte	Name	Meaning
0	LAT_0	32-bit signed integer base station latitude, in milli-arcseconds. This value is used as the reference latitude for the DGPS correction.
1	LAT_1	
2	LAT_2	
3	LAT_3	
4	LON_0	32-bit signed integer base station longitude, in milli-arcseconds. This value is used as the reference longitude for the DGPS correction.
5	LON_1	
6	LON_2	
7	LON_3	
8	Height_0	32-bit signed integer base station altitude, in centimeters above WGS-84. This value is used as the reference altitude for the DGPS correction.
9	Height_1	
10	Height_2	
11	Height_3	
12	Enable	Non-zero to enable DGPS mode, zero to disable.

3.1.3.5 Dynamic Enumeration

This packet is used to enable or disable the dynamic enumeration feature of the groundstation. When dynamic enumeration is on, the ground station will periodically broadcast a message requesting any avionics that are not currently in communications to reply. Any avionics which reply are automatically added to the polling list. In addition, when dynamic enumeration is on,

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any avionics which is not replying will be automatically removed from the list.. The ground station will reply by echoing this packet.

Table 16. Spectrum analyzer packet

Byte	Name	Meaning
0	EnumerationON	One to turn enumeration on, Zero to turn it off.

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4 Avionics communications

4.1 Pilot in the loop stream

The ground station samples the pilot's console, forms the pilot command packet from the console data, and sends that data to the pilot in loop stream on the avionics. All pilot in the loop stream packets follow the format in Table 17.

Table 17. Pilot in loop stream packet

Byte	Name	Meaning
0	SYNC	Synchronization character used to signal the receiving pilot stream that a packet *may* be forthcoming. Must be 0xA0.
1	SYNC1	Second synchronization character used to signal the receiving pilot stream that a packet *may* be forthcoming. Must be 0x05
2	PacketType	Command and control packet type, see Table 18.
3	Size	The number of payload bytes in the pilot packet.
4…Size+3	Payload	Size payload bytes
Size+4	CRCHi	Most and Least significant byte of the cyclic redundancy check, respectively. The CRC applies to bytes 0…Size+3.
Size+5	CRCLo	

Table 18. Pilot in the loop stream packet types

Name	Value	Meaning
PILOT_COMMAND_ANGLE	0	Pilot commands in angle form.
PILOT_COMMAND_PULSE	1	Pilot commands in pulse width form.

In addition to the pilot pulse command packet formed automatically by the ground station users can send their own pilot command data, either in pulse or angle form. However the ground station will intercept and discard any user supplied pilot command data addressed to the pilot address if the pilot console has manual control selected.

Note that the packets contain 5 commands, intended for a conventional aircraft. All of the mixing required to generate the 10 servo outputs as well as the non-conventional configurations, is performed onboard the *Piccolo*.

4.1.1 Pilot command angle

Table 20 gives the pilot angle command packet. This packet gives the pilot command as a set of control surface angles.

Table 19. Pilot angle command packet

Byte	Name	Meaning
0	Aileron_0	16-bit signed aileron command in milli-radians.
1	Aileron_1	
2	Elevator_0	16-bit signed elevator command in milli-radians.
3	Elevator_1	
4	Throttle_0	16-bit signed throttle command in units of 0.001% of full

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5	Throttle_1	throw.
6	Rudder_0	16-bit signed rudder command in milli-radians.
7	Rudder_1	
8	Flap_0	16-bit signed flap command in milli-radians.
9	Flap_1	
10	Manual	Nonzero for manual control, i.e. nonzero to use the data in this packet.
11	Reserved	
12	Brakes_0	16-bit signed brakes command in units of 0.001% of full throw. 0 is brakes off.
13	Brakes_1	
14	Parachute_0	16-bit signed paracute command in units of 0.001% of full throw. 1 is parachute deployed.
15	Parachute_1	
16	Ignition	Nonzero for ignition on.

4.1.2 Pilot command pulse

Table 20 gives the pilot pulse command packet. This packet gives the pilot command as a set of pulse widths sampled from the pilot console by the ground station.

Table 20. Pilot pulse command packet

Byte	Name	Meaning
0	Aileron_0	16-bit unsigned aileron pulse width in microseconds.
1	Aileron_1	
2	Elevator_0	Elevator pulse width.
3	Elevator_1	
4	Throttle_0	Throttle pulse width.
5	Throttle_1	
6	Rudder_0	Rudder pulse width.
7	Rudder_1	
8	Flap_0	Flap pulse width.
9	Flap_1	
10	Manual	Nonzero if the autopilot selection switch indicates manual control.
11	Reserved	
12	Brakes_0	Brakes pulse width.
13	Brakes_1	
14	Parachute_0	Parachute pulse width.
15	Parachute_1	
16	Ignition	Nonzero if the ignition select switch indicates ignition on.

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4.2 Autopilot stream

The autopilot stream is used to carry system commands from the operator interface to the avionics, autopilot state information from the avionics to the operator interface, and sensor telemetry information from the avionics to the operator interface. It defines many different packet types, each of which follows the format given in Table 21.

Table 21. Autopilot stream packet definition

Byte	Name	Meaning
0	SYNC	Synchronization character used to signal the receiving autopilot stream that a packet *may* be forthcoming. Must be 0xA0.
1	SYNC1	Second synchronization character used to signal the receiving autopilot stream that a packet *may* be forthcoming. Must be 0x05.
2	PacketType	Command and control packet type, see Table 22.
3	Size	The number of payload bytes in the autopilot packet.
4…Size+3	Payload	Size payload bytes
Size+4	CRCHi	Most and Least significant byte of the cyclic redundancy check, respectively. The CRC applies to bytes 0…Size+3.
Size+5	CRCLo	

Table 22. Autopilot stream packet types

Name	#	Dir	Period	Meaning
Reserved	0			
Reserved	1			
BANDWIDTH_MODE	2	Both	N/A	Configure the bandwidth mode
Reserved	3			
Reserved	4			
ACTUATOR_TABLE	5	Both	N/A	Control surface calibration
Reserved	6			
Reserved	7			
WAYPOINT	8	Both	N/A	Waypoint data
WAYPOINT_LIST	9	Both	N/A	List of waypoint indexes
TRACK	10	Up	N/A	Tracker command
Reserved	11			
Reserved	12			
Reserved	13			
SENSOR_ORIENTATION	14	Both	N/A	Avionics installation orientation
ALTIMETER_SETTING	15	Both	N/A	Altimeter base pressure setting
SYSTEM_RESET	16	Up		System reset command
SYSTEM_VERSION	17	Both	N/A	System hardware and software version
RESET_REPORT	18	Down	N/A	System reset report, once per reset
SURFACE_TEST	19	Up		Control surface test
MISSION_LIMITS	20	Both	N/A	Mission Limits
Reserved	21			
Reserved	22			
Reserved	23			
AUTOPILOT_LOOP	24	Up	N/A	Individual autopilot loop control
Reserved	25			
DESCRIPTION	26	Both	N/A	Configuration description string

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USER_SPACE	27	Both	N/A	Nonvolatile user data space
Reserved	28			
Reserved	29			
MAG_CALIBRATION	30	Both	N/A	Magnetometer calibration
ENGINE_KILL	31	Up	N/A	Engine kill command
RADIO_TRANSMIT_DISABLE	32			Enable/disable radio transmit
RADIO_SETTINGS	33	Both	N/A	Radio hopping pattern and channel
EXTERNAL_SERIAL_SETUP	34	Both	N/A	External serial port setup
EXTERNAL_IO_SETUP	35	Both	N/A	IO control setup
EXTERNAL_IO_SAMPLE	36	Down	N/A	IO sampling
Reserved	37			
EXTERNAL_ADC_SAMPLE	38	Down	N/A	ADC IO sampling
LAND_NOW	39	Up	N/A	Landing command
Reserved	40			
Reserved	41			
Reserved	42			
CREATE_SIMPLE_LANDING	43	Up	N/A	Create a landing pattern using onboard settings.
Reserved	44			
AIR_DATA_ZERO	45	Up	N/A	Zero the air data sensors only
PRE_LAUNCH_MODE	46	Up	N/A	Autopilot mode command
MANUAL_ASSIST_MODE	47	Up	N/A	Manual assist mode
LIGHTS_CMD	48	Up	N/A	Lights on/off command
BRAKES_CMD	49	Up	N/A	Brakes on/off command
PARACHUTE_CMD	50	Up	N/A	Parachute deploy/retract command
DROP_CMD	51	Up	N/A	Drop function deploy/retract command
THROTTLE_TRIM	52	Up	N/A	Set the throttle trim
Reserved	53			
Reserved	54			
Reserved	55			
Reserved	56			
Reserved	57			
Reserved	58			
TRANSPONDER_CONTROL	59	Both	N/A	Transponder settings
Reserved	60			
RAW_VIBRATION_DATA	61	Down	N/A	Raw vibration data
VIBRATION_DATA	62	Down	N/A	FFT vibration data
LINK_BRIDGE	63	Both	N/A	Relay from one link to another
DOUBLET_CMD	64	Up	N/A	Doublet command
DOUBLET_AP_DATA	65	Down	N/A	Low speed doublet data
DOUBLET_SENSOR_DATA	66	Down	N/A	High speed doublet data
CONTROLLER_DATA_REQUEST	67	Up	N/A	Request controller data
COTNROLLER_DATA	68	Both	N/A	Controller data
TELEMETRY_HI_RES	69	Down	0.05-1	Standard telemetry, high resolution
TELEMETRY_LO_RES	70	Down	0.05-3	Standard telemetry, low resolution
SYSTEM_STATUS_HI_RES	71	Down	6-18	System status, high resolution
SYSTEM_STATUS_LO_RES	72	Down	2-6	System status, low resolution
LAUNCH_NOW	73	Up	N/A	Launch command
CONTROLLER_DATA_DEFAULT	74	Up	N/A	Default controller data
SET_FUEL_LEVEL	75	Up	N/A	Used to set the fuel level
SENSOR_ERROR	76	Both	N/A	Used to set some sensor error information
ABORT	77	Both	N/A	Issue the abort command

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4.2.1 Number encoding

Numbers in the autopilot stream packets use different formats. All formats use BIG-ENDIAN byte order in which the most significant byte of a word appears first. Integers are given as either unsigned or signed (two's complement) in 8, 16, or 32 bits. Some integers are given as unsigned 24 bits. Integers are usually scaled in order to make the range of the number match the range of the property being encoded.

In some cases floating point numbers are used for values with wide dynamic ranges that cannot be properly scaled until the system is operating. These numbers are either IEEE-754 32-bit floating point, or a special 16-bit floating point format given below:

	Sign	Exponent	Mantissa
Bit	0	1 2 3 4 5 6	7 8 9 A B C D E F
Range	-1/1	-31…31	0…511

This format can represent numbers from 2^{31} to 2^{-31} with 9-bits of precision. A zero is represented with a mantissa and exponent of zero. The exponent is biased with 31 and the mantissa assumes a left most leading 1. This definition exactly matches the IEEE floating point formats, except the range of the fields has been reduced.

Converting from IEEE-754 32-bit format to the 16-bit format is done by splitting the IEEE number into its component parts: sign, exponent, and mantissa. The mantissa is right shifted 14-bits, losing that resolution. The exponent is then unbiased (IEEE-754 uses a bias of 127) and re-biased with 31. The 16-bit format is then assembled from the original sign bit, the new exponent, and the new mantissa. During the re-biasing of the exponent under flow and overflow is detected. Underflows should result in positive zero. Overflows should result in the maximum possible exponent.

4.2.2 Packets sent periodically

The packets listed in this section are sent periodically by the autopilot. The rate at which these packets are sent is a function of the available telemetry bandwidth, and the resolution mode, either high or low. The system will dynamically scale the bandwidth mode to take maximum advantage of the available telemetry bandwidth.

Table 23. High resolution telemetry bandwidth modes.

Mode	Packets	Period (s)	Size	Bandwidth
0	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	0.05 6 2 (except long)	114 + 6 88 + 6 32 + 6	24000 157 127 24284
1	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	0.1 6 2 (except long)	114 + 6 88 + 6 32 + 6	12000 157 127 12284
2	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	0.2 6 2 (except long)	114 + 6 88 + 6 32 + 6	6000 157 127 6284
3	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long	0.5 6	114 + 6 88 + 6	2400 157

	SYSTEM_STATUS_HI_RES short	2 (except long)	32 + 6	127 2684
4	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	1 6 2 (except long)	114 + 6 88 + 6 32 + 6	1200 157 127 1484
5	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	2 12 4 (except long)	114 + 6 88 + 6 32 + 6	600 79 79 742
6	TELEMETRY_HI_RES SYSTEM_STATUS_HI_RES long SYSTEM_STATUS_HI_RES short	3 18 6 (except long)	114 + 6 88 + 6 32 + 6	400 52 52 495

Table 24. Low resolution telemetry bandwidth modes.

Mode	Packets	Period (s)	Size	Bandwidth
0	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	0.05 6 2 (except long)	66+6 64+6 32+6	14400 120 127 14647
1	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	0.1 6 2 (except long)	66+6 64+6 32+6	7200 120 127 7447
2	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	0.2 6 2 (except long)	66+6 64+6 32+6	3600 120 127 3847
3	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	0.5 6 2 (except long)	66+6 64+6 32+6	1440 120 127 1687
4	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	1 6 2 (except long)	66+6 64+6 32+6	720 120 127 967
5	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	2 12 4 (except long)	66+6 64+6 32+6	360 60 64 484
6	TELEMETRY_LO_RES SYSTEM_STATUS_LO_RES long SYSTEM_STATUS_LO_RES short	3 18 6 (except long)	66+6 64+6 32+6	240 40 41 321

4.2.2.1 TELEMETRY_HI_RES

This is the standard high resolution telemetry packet sent by the autopilot. The period at which it is sent depends on the available telemetry bandwidth.

Byte	Name	Meaning

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0	Data flags	Data flags bit field indicates data in packet: • Bit 0: Set if packet includes GPS data (bytes 8-35) • Bit 1: Set if packet includes calculated sensor data (bytes 36 - 55) • Bit 2: Set if packet includes raw sensor data (bytes 56-73) • Bit 3: Set if packet includes data from magnetometer (bytes 74 - 81). • Bit 4: Set if packet includes AGL data. • Bit 5: Set if packet includes fuel data. • Bit 6-7: reserved.
1	NumAct	The number of actuators included in the packet, zero if no actuator data is included.
2	Limits_0	16-bit telemetry limits bit field, set if true. Bit 0: Altitude is too low. Bit 1: Altitude is too high. Bit 2: Indicated air speed is too low. Bit 3: Indicated air speed is too high. Bit 4: Roll angle is too large. Bit 5: Pitch angle is too large. Bit 6: Engine RPM is too low. Bit 7: Engine RPM is too high. Bit 8: Winds are excessive. Bit 9-31: reserved.
3	Limits_1	
4	Time_0	32-bit unsigned time since reset in milliseconds.
5	Time_1	
6	Time_2	
7	Time_3	
8	LAT_0	32-bit signed integer latitude, in milli-arcseconds. This data come from the GPS/INS navigation filter, not directly from the GPS.
9	LAT_1	
10	LAT_2	
11	LAT_3	
12	LON_0	32-bit signed integer longitude, in milli-arcseconds. This data come from the GPS/INS navigation filter, not directly from the GPS.
13	LON_1	
14	LON_2	
15	LON_3	
16	Height_0	24-bit unsigned height, in centimeters above 1000 meters below WGS-84. This data come from the GPS/INS navigation filter, not directly from the GPS.
17	Height_1	
18	Height_2	
19	Reserved	
20	Sats_0	Satellite status bit field
21	Sats_1	Bit 0:5 — Dilution of precision, in units of 0.2 DOP. Bit 6:10 — Number of visible satellites Bit 11:15 — Number of tracked satellites
22	Vnorth_0	16-bit signed integer North component of the groundspeed, in centimeters per second.
23	Vnorth_1	
24	VEast_0	16-bit signed integer East component of the groundspeed, in centimeters per second.
25	VEast_1	
26	VDown_0	16-bit signed integer Down component of the groundspeed, in centimeters per second.
27	VDown_1	
28	STATUS_0	16-bit GPS status word.

29	STATUS_1	• Bit 0-2 (msb): 111 = 3D Fix 110 = 2D Fix 101 = Propagate Mode 100 = Position Hold 011 = Acquiring Satellites 010 = Bad Geometry 001 = Reserved 000 = Reserved • Bit 3: Set if dead-reckoned • Bit 4: Set if satellite based augmentation system • Bit 5: Reserved • Bit 6: Fast acquisition position • Bit 7: GPS data are raw (unfiltered) • Bit 8: GPS is performing cold start • Bit 9: GPS is differentially corrected • Bit 10: Position lock mode enabled • Bit 11: Auto survey mode • Bit 12: Insufficient satellites visible • Bit 13-14: 11 = No antenna power 10 = Antenna undercurrent 01 = Antenna overcurrent 00 = Antenna good • Bit 15: Reserved
30	GPSWeek_0	16-bit unsigned GPS week number.
31	GPSWeek_1	
32	GPSTOW_0	32-bit unsigned GPS time of week in milliseconds. This time represents the time of the data in this packet, not necessarily the time of the last GPS report.
33	GPSTOW_1	
34	GPSTOW_2	
35	GPSTOW_3	
36	ROLL_0	16-bit signed Euler roll angle in units of 1/10000th radian, -PI to PI.
37	ROLL_1	
38	PITCH_0	16-bit signed Euler pitch angle in units of 1/10000th radian, -PI/2 to PI/2.
39	PITCH_1	
40	YAW_0	16-bit unsigned Euler yaw angle in units of 1/10000th radian, 0 to 2PI.
41	YAW_1	
42	ALT_0	16-bit signed barometric altitude above GPS altitude, in centimeters.
43	ALT_1	
44	WSouth_0	16-bit signed integer component of the wind coming from the South, in centimeters per second.
45	WSouth_1	
46	WWest_0	16-bit signed integer component of the wind coming from the West, in centimeters per second.
47	WWest_1	
48	LeftRPM_0	16-bit unsigned left engine RPM.
49	LeftRPM_1	
50	RightRPM_0	16-bit unsigned right engine RPM.
51	RightRPM_1	
52	Density ratio	8-bit unsigned density ratio in 1/200ths. i.e. 200 = standard sea level density (1.225 kg/m^3).
53	OAT	Outside air temperature as a signed 8 bit number in degrees Celsius (-128 to 127).
54	IAS_0	16-bit unsigned indicated air speed (IAS), in centimeters per second, starting at -2000 cm/s.
55	IAS_1	
56	StaticP_0	16-bit unsigned static pressure in units of 2 Pascals.
57	StaticP_1	

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58	RollRate_0	16-bit signed roll rate in 1/10000th radians/s
59	RollRate_1	
60	PitchRate_0	16-bit signed pitch rate in 1/10000th radians/s
61	PitchRate_1	
62	YawRate_0	16-bit signed yaw rate in 1/10000th radians/s
63	YawRate_1	
64	Xaccel_0	16-bit signed x-axis acceleration in 0.005 meters per second per second.
65	Xaccel_1	
66	Yaccel_0	16-bit signed y-axis acceleration in 0.005 meters per second per second.
67	Yaccel_1	
68	Zaccel_0	16-bit signed z-axis acceleration in 0.005 meters per second per second.
69	Zaccel_1	
70	XMagField_0	Signed 16-bit X-axis magnetic field in tenths of a milli-Gauss.
71	XMagField_1	
72	YMagField_0	Signed 16-bit Y-axis magnetic field in tenths of a milli-Gauss.
73	YMagField_1	
74	ZMagField_0	Signed 16-bit Z-axis magnetic field in tenths of a milli-Gauss.
75	ZmagField_1	
76	Compass_0	16-bit unsigned true heading from the magnetometer in units of 1/10000th radian, 0 to 2PI.
77	Compass_1	
78	Agl_0	16-bit unsigned height above ground from the sonic altimeter or radar altimeter in centimeters.
79	Agl_1	
80	Actuator0_0	16-bit signed actuator 0 position in 1/10000th
81	Actuator0_1	
82	Actuator1_0	16-bit signed actuator 1 position in 1/10000th
83	Actuator1_1	
84	Actuator2_0	16-bit signed actuator 2 position in 1/10000th
85	Actuator2_1	
86	Actuator3_0	16-bit signed actuator 3 position in 1/10000th
87	Actuator3_1	
88	Actuator4_0	16-bit signed actuator 4 position in 1/10000th
89	Actuator4_1	
90	Actuator5_0	16-bit signed actuator 5 position in 1/10000th
91	Actuator5_1	
92	Actuator6_0	16-bit signed actuator 6 position in 1/10000th
93	Actuator6_1	
94	Actuator7_0	16-bit signed actuator 7 position in 1/10000th
95	Actuator7_1	
96	Actuator8_0	16-bit signed actuator 8 position in 1/10000th
97	Actuator8_1	
98	Actuator9_0	16-bit signed actuator 9 position in 1/10000th
99	Actuator9_1	
100	Actuator10_0	16-bit signed actuator 10 position in 1/10000th
101	Actuator10_1	
102	Actuator11_0	16-bit signed actuator 11 position in 1/10000th
103	Actuator11_1	
104	Actuator12_0	16-bit signed actuator 12 position in 1/10000th
105	Actuator12_1	
106	Actuator13_0	16-bit signed actuator 13 position in 1/10000th
107	Actuator13_1	
108	Actuator14_0	16-bit signed actuator 14 position in 1/10000th
109	Actuator14_1	
110	Actuator15_0	16-bit signed actuator 15 position in 1/10000th
111	Actuator15_1	

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112	FuelFlow_0	16-bit floating point (see 4.2.1) rate at which fuel or power is flowing. If positive than number represents fuel flow in grams per hour. If negative than number represents Watts of electrical power.
113	FuelFlow_1	
114	Fuel_0	16-bit floating point (see 4.2.1) fuel remaining. If fuel flow is positive than this number is the fuel remaining in kilograms. If fuel flow is negative this number is charge remaining in Watt-Hours.
115	Fuel_1	

4.2.2.2 TELEMETRY_LO_RES

Byte	Name	Meaning
0	Data flags	Data flags bit field indicates data in packet: • Bit 0: Set if packet includes GPS data (bytes 5-25) • Bit 1: Set if packet includes calculated sensor data (bytes 26 - 34) • Bit 2: Set if packet includes raw sensor data (bytes 35-44) • Bit 3: Set if packet includes data from magnetometer (bytes 45 - 48). • Bit 4: Set if packet includes AGL data. • Bit 5: Set if packet includes fuel data.
1	NumAct	The number of actuators included in the packet, zero if no actuator data is included.
2	Limits_0	16-bit telemetry limits bit field, set if true. Bit 0: Altitude is too low. Bit 1: Altitude is too high. Bit 2: Indicated air speed is too low. Bit 3: Indicated air speed is too high. Bit 4: Roll angle is too large. Bit 5: Pitch angle is too large. Bit 6: Engine RPM is too low. Bit 7: Engine RPM is too high. Bit 8: Winds are excessive. Bit 9-31: reserved.
3	Limits_1	
4	Time_0	24-bit unsigned time since the system started in units of 0.01 seconds. From 0 to 419430.4 seconds (roughly 46 hours).
5	Time_1	
6	Time_3	
7	LAT_0	24-bit unsigned latitude. 24-bit latitude is formed according to: Lat24 = (Latitude + PI) * (16777216/2PI). This yields a resolution of 2.4 meters at the equator.
8	LAT_1	
9	LAT_2	
10	LON_0	24-bit unsigned longitude. 24-bit longitude is formed according to: Lon24 = (Longitude + PI) * (16777216/2PI). This yields a resolution of 2.4 meters at the equator.
11	LON_1	
12	LON_2	
13	Height_0	16-bit unsigned height, in 0.5 meters above 1000 meters below WGS-84. Height16 = (Height + 1000)*2.0.
14	Height_1	
15	Sats_0	Satellite status bit field
16	Sats_1	Bit 0:5 — Dilution of precision, in units of 0.2 DOP. Bit 6:10 — Number of visible satellites Bit 11:15 — Number of tracked satellites
17	VNorth	8-bit signed integer North component of the groundspeed, in meters per second.
18	VEast	8-bit signed integer East component of the groundspeed, in meters per second.

19	VDown	8-bit signed integer Down component of the groundspeed, in meters per second.
20	STATUS_0	16-bit GPS status word. • Bit 0-2 (msb): 111 = 3D Fix 110 = 2D Fix 101 = Propagate Mode 100 = Position Hold 011 = Acquiring Satellites 010 = Bad Geometry 001 = Reserved 000 = Reserved • Bit 3: Set if dead-reckoned • Bit 4: Set if satellite based augmentation system • Bit 5: Reserved • Bit 6: Fast acquisition position • Bit 7: GPS data are raw (unfiltered) • Bit 8: GPS is performing cold start • Bit 9: GPS is differentially corrected • Bit 10: Position lock mode enabled • Bit 11: Auto survey mode • Bit 12: Insufficient satellites visible • Bit 13-14: 11 = No antenna power 10 = Antenna undercurrent 01 = Antenna overcurrent 00 = Antenna good • Bit 15: Reserved
21	STATUS_1	
22	GPSWeek_0	16-bit unsigned GPS week number.
23	GPSWeek_1	
24	GPSTOW_0	32-bit unsigned GPS time of week in milliseconds.
25	GPSTOW_1	
26	GPSTOW_2	
27	GPSTOW_3	
28	Roll	8-bit signed integer roll angle in units of (360/256) degrees per LSB (-180 to 180).
29	Pitch	8-bit signed integer pitch angle in units of (180/256) degrees per LSB (-90 to 90).
30	Yaw	8-bit unsigned integer yaw angle in units of (360/256) degrees per LSB (0 to 360).
31	Alt	8-bit signed barometric altitude difference from height, in 0.5 meters.
32	WSouth	8-bit signed integer estimate of wind from the South in units of 0.5 meters per second.
33	WWest	8-bit signed integer estimate of wind from the West in units of 0.5 meters per second.
34	LeftRPM	8-bit unsigned engine RPM in units of 50 revolutions per minute
35	RightRPM	8-bit unsigned engine RPM in units of 50 revolutions per minute
36	Density ratio	8-bit unsigned density ratio in 1/200ths. i.e. 200 = standard sea level density (1.225 kg/m^3).
37	OAT	Outside air temperature as a signed 8 bit number in degrees Celsius (-128 to 127).

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38	IAS	8-bit unsigned indicated air speed in m/s from -20 m/s to 225 m/s
39	StaticP_0	16-bit unsigned static pressure in units of 2 Pascals.
40	StaticP_1	
41	RollRate	8-bit signed roll rate in units of 2 deg/s.
42	PitchRate	8-bit signed pitch rate in units of 2 deg/s.
43	YawRate	8-bit signed yaw rate in units of 2 deg/s.
44	Xaccel	8-bit signed x-axis acceleration in units of 0.2 m/s/s
45	Yaccel	8-bit signed y-axis acceleration in units of 0.2 m/s/s
46	Zaccel	8-bit signed z-axis acceleration in units of 0.5 m/s/s
47	XmagField	8-bit signed x-axis magnetic field in 0.01 Guass.
48	YmagField	8-bit signed y-axis magnetic field in 0.01 Gauss
49	ZmagField	8-bit signed z-axis magnetic field in 0.01 Gauss
50	Compass	8-bit unsigned true heading from the magnetometer in units of (360/256) degrees per LSB (0 to 360).
51	AGL	8-bit unsigned altitude above ground from the sonic or radar altimeter in units of 0.1 meters.
52	Actuator0	8-bit signed actuator 0 position in 1/100th.
53	Actuator1	8-bit signed actuator 1 position in 1/100th.
54	Actuator2	8-bit signed actuator 2 position in 1/100th.
55	Actuator3	8-bit signed actuator 3 position in 1/100th.
56	Actuator4	8-bit signed actuator 4 position in 1/100th.
57	Actuator5	8-bit signed actuator 5 position in 1/100th.
58	Actuator6	8-bit signed actuator 6 position in 1/100th.
59	Actuator7	8-bit signed actuator 7 position in 1/100th.
60	Actuator8	8-bit signed actuator 8 position in 1/100th.
61	Actuator9	8-bit signed actuator 9 position in 1/100th.
62	Actuator10	8-bit signed actuator 10 position in 1/100th.
63	Actuator11	8-bit signed actuator 11 position in 1/100th.
64	Actuator12	8-bit signed actuator 12 position in 1/100th.
65	Actuator13	8-bit signed actuator 13 position in 1/100th.
66	Actuator14	8-bit signed actuator 14 position in 1/100th.
67	Actuator15	8-bit signed actuator 15 position in 1/100th.
68	FuelFlow_0	16-bit floating point (see 4.2.1) rate at which fuel or power is flowing. If positive than number represents fuel flow in grams per hour. If negative than number represents Watts of electrical power.
69	FuelFlow_1	
70	Fuel_0	16-bit floating point (see 4.2.1) fuel remaining. If fuel flow is positive than this number is the fuel remaining in kilograms. If fuel flow is negative this number is charge remaining in Watt-Hours.
71	Fuel_1	

4.2.2.3 SYSTEM_STATUS

The system status packet is used to indicate the status and command settings of the autopilot. The strict interpretation of the packet depends on its size and on the controller sending it. The packet supports up to 8 different control loops, not counting the navigation loop. There are two versions of the packet: short, and long. The long version of the packet is sent every six seconds The short version of the packet is sent every 2 seconds (except when the long is sent). The short version of the packet is 32 bytes long and is primarily used to indicate status of the system. The long version of the packet is at least 56 bytes long and may be up to 88 bytes long. The difference in length depends on the number of loops that the system is reporting for. The packet (either short or long as needed) will also be sent whenever a state change occurs.

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Table 25. System Status

Byte	Name	Meaning
0	MainPower_0	24-bit main power input bit field: Bit 0-11: 12-bit current in 1000ths of an Amp. Bit 12-23: 12-bit voltage in 100ths of a Volt.
1	MainPower_1	
2	MainPower_2	
3	ServoPower_0	24-bit servo power input bit field: Bit 0-11: 12-bit current in 1000ths of an Amp. Bit 12-23: 12-bit voltage in 100ths of a Volt.
4	ServoPower_1	
5	ServoPower_2	
6	InternalV	Internal voltage bit field, set if bad: Bit 0: First stage converter voltage. Bit 1: 5.0 digital voltage. Bit 2: 5.0 analog voltage. Bit 3: CPU voltage. Bit 4: GPS voltage. Bit 5-7: reserved
7	BoardT	Piccolo board temperature as a signed 8 bit number in degrees Celsius (-128 to 127).
8	DataSource	Navigation source data, set to indicate external Bit 0: IMU source. Bit 1: GPS source. Bit 2: Air data source. Bit 3: Mag data source. Bit 4-7: reserved.
9	NavHealth_0	16 bit navigation health information, bit set to indicate residual error or covariance is within bounds. Bit 0: Position. Bit 1: Velocity. Bit 2: Baro. Bit 3: TAS. Bit 4: AGL. Bit 5: Magnetometer. Bit 6: Heading. Bit 7: Attitude. Bit 8: Gyro bias. Bit 9: Accelerometer bias. Bit 10: Magnetometer bias. Bit 11: Wind. Bit 12-15: Filter mode: init, align, ready, normal, AHRS.
10	NavHealth_1	
11	NovatelStatus	Navigation health information for external GPS or GPS/INS 5 MSB's: Novatel Solution Status 3 LSB's: Novatel INS Status
12	SolutionType	External GPS/INS solution type (Novatel Solution Type)
13	Reserved	
14	RSSI	Receive signal strength indicator for the internal datalink, as a signed 8 bit number in dBm.
15	VSWR	8-bit unsigned datalink VSWR in units of 0.02. If zero then VSWR is not available.
16	LoopStatus_0	16-bit loop status bit field: 0 = off, 1 = on, 2 = auto

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17	LoopStatus_1	Bit 0-1: 1st loop status. Bit 2-3: 2nd loop status. Bit 4-5: 3rd loop status. Bit 6-7: 4th loop status. Bit 8-9: 5th loop status. Bit 10-11: 6th loop status. Bit 12-13: 7th loop status. Bit 14-15: 8th loop status.
18	LoopTelem_0	16-bit loop telemetry status bit field, set if true.
19	LoopTelem_1	Bit 0: 1st loop is less than min limit. Bit 1: 1st loop is more than max limit. Bit 2: 2nd loop is less than min limit. Bit 3: 2nd loop is more than max limit. Bit 4: 3rd loop is less than min limit. Bit 5: 3rd loop is more than max limit. Bit 6: 4th loop is less than min limit. Bit 7: 4th loop is more than max limit. Bit 8: 5th loop is less than min limit. Bit 9: 5th loop is more than max limit. Bit 10: 6th loop is less than min limit. Bit 11: 6th loop is more than max limit. Bit 12: 7th loop is less than min limit. Bit 13: 7th loop is more than max limit. Bit 14: 8th loop is less than min limit. Bit 15: 8th loop is more than max limit.
20	Num loops	The number of loops that this controller supports (0-8).
21	GlobalStatus	8-bit Global status Bit 0: Global on. Bit 1-2: 2-bit manual assist mode: • Standard: no manual assistance. • Lateral. • Longitudinal. • All: Lateral and Longitudinal. Bit 3-7: 5-bit autopilot mode. Mode 0 is pre-launch all other modes are controller specific.
22	Actions_1	16-bit action status
23	Actions_2	Bit 0: Reserved Bit 1: Launch action 1 Bit 2: Launch action 2 Bit 3: Drop deployed Bit 4: Lights active Bit 5: Engine kill active Bit 6: Parachute deployed Bit 7: Parachute pending RPM Bit 9-15: Brakes 0 (off) to 100 (full)
24	Failure	Bit 0: Flight termination asserted Bit 1: Deadman output is on. Bit 2: GPS timeout has elapsed. Bit 3: Communications timeout has elapsed. Bit 4: Manual pilot has killed the engine. Bit 5: Autopilot has killed the engine. Bit 6: Operator has killed the engine. Bit 7: Reserved.
25	Reserved	
26	Tracker_0	16-bit tracker status bit field:

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27	Tracker_1	Bit 0-1: Tracker loop status, off, on, auto. Bit 2-8: Index of waypoint from 0-99. Bit 9-15:Index of waypoint to 0-99.
28	TrackStatus_0	16-bit track status bit field: Bit 0: Set if the system is orbiting (or hovering). Bit 1-15: ETA to waypoint in seconds, or time remaining in orbit if performing timed orbit. If orbit is untimed this value is zero.
29	TrackStatus_1	
30	RollBias	8-bit signed roll rate bias in $1/1000^{th}$ radian/s
31	PitchBias	8-bit signed pitch rate bias in $1/1000^{th}$ radian/s
32	YawBias	8-bit signed yaw rate bias in $1/1000^{th}$ radian/s
33	X_accelBias	8-bit signed x acceleration bias in $1/100^{th}$ m/s/s
34	Y_accelBias	8-bit signed y acceleration bias in $1/100^{th}$ m/s/s
35	Z_accelBias	8-bit signed z acceleration bias in $1/100^{th}$ m/s/s
36	X_magBias	8-bit signed x magnetic field bias in 1 mGuass
37	Y_magBias	8-bit signed y magnetic field bias in 1 mGuass
38	Z_magBias	8-bit signed z magnetic field bias in 1 mGuass
39	Reserved	
40	HorizStdDev_0	16-bit floating point (see 4.2.1) Horizontal position standard deviation (meters).
41	HorizStdDev_1	
42	VertStdDev_0	16-bit floating point (see 4.2.1) Vertical position standard deviation (meters).
43	VertStdDev_1	
44	StartLat_0	32-bit signed integer latitude of the start of the track segment, in milli-arcseconds. If the tracker loop control is off then this data is not valid.
45	StartLat_1	
46	StartLat_2	
47	StartLat_3	
48	StartLon_0	32-bit signed integer longitude of the start of the track segment, in milli-arcseconds. If the tracker loop control is off then this data is not valid.
49	StartLon_1	
50	StartLon_2	
51	StartLon_3	
52	Reserved	
53	StartAlt_0	24-bit unsigned altitude of the start of the track segment, in centimeters above 1000 meters below WGS-84.
54	StartAlt_1	
55	StartAlt_2	
56	DestLat_0	32-bit signed integer latitude of the destination waypoint, in milli-arcseconds. If the tracker loop control is off then this data is not valid.
57	DestLat_1	
58	DestLat_2	
59	DestLat_3	
60	DestLon_0	32-bit signed integer longitude of the destination waypoint, in milli-arcseconds. If the tracker loop control is off then this data is not valid.
61	DestLon_1	
62	DestLon_2	
63	DestLon_3	
64	Reserved	
65	DestAlt_0	24-bit unsigned altitude of the destination waypoint, in centimeters above 1000 meters below WGS-84.
66	DestAlt_1	
67	DestAlt_2	
68	Target0_0	32-bit single precision floating point 1^{st} loop target. The interpretation is controller specific
69	Target0_1	
70	Target0_2	
71	Target0_3	
72	Target1_0	32-bit single precision floating point 2^{nd} loop target. The interpretation is controller specific
73	Target1_1	
74	Target1_2	
75	Target1_3	

76	Target2_0	32-bit single precision floating point 3rd loop target. The interpretation is controller specific
77	Target2_1	
78	Target2_2	
79	Target2_3	
80	Target3_0	32-bit single precision floating point 4th loop target. The interpretation is controller specific
81	Target3_1	
82	Target3_2	
83	Target3_3	
84	Target4_0	32-bit single precision floating point 5th loop target. The interpretation is controller specific
85	Target4_1	
86	Target4_2	
87	Target4_3	
88	Target5_0	32-bit single precision floating point 6th loop target. The interpretation is controller specific
89	Target5_1	
90	Target5_2	
91	Target5_3	
92	Target6_0	32-bit single precision floating point 7th loop target. The interpretation is controller specific
93	Target6_1	
94	Target6_2	
95	Target6_3	
96	Target7_0	32-bit single precision floating point 8th loop target. The interpretation is controller specific
97	Target7_1	
98	Target7_2	
99	Target7_3	

4.2.2.4 SYSTEM_STATUS_LO_RES

The low resolution system status packet gives the same data as the standard system status packet, but with less resolution for bandwidth constrained cases. It has a short and a long form which are 32 and 64 bytes long respectively. The long form is variable length according to the number of loops encoded. Loop targets for this packet are encoded as 16-bit floating point numbers in which the significand occupies the lower nine bits.

Table 26. Low resolution system status

Byte	Name	Meaning
0	MainPower_0	24-bit main power input bit field: Bit 0-9: 12-bit current in 1000ths of an Amp. Bit 10-23: 12-bit voltage in 100ths of a Volt.
1	MainPower_1	
2	MainPower_2	
3	ServoPower_0	24-bit servo power input bit field: Bit 0-11: 12-bit current in 1000ths of an Amp. Bit 12-23: 12-bit voltage in 100ths of a Volt.
4	ServoPower_1	
5	ServoPower_2	
6	InternalV	Internal voltage bit field, set if bad: Bit 0 First stage converter voltage. Bit 1 5.0 digital voltage. Bit 2 5.0 analog voltage. Bit 3 CPU voltage. Bit 4 GPS voltage.
7	BoardT	Piccolo board temperature as a signed 8 bit number in degrees Celsius (-128 to 127).

8	DataSource	Navigation source data, set to indicate external Bit 0: IMU source. Bit 1: GPS source. Bit 2: Air data source. Bit 3: Mag data source. Bit 4-7: reserved.
9	NavHealth_0	16 bit navigation health information, bit set to indicate residual error or covariance is within bounds. Bit 0: Position. Bit 1: Velocity. Bit 2: Baro. Bit 3: TAS. Bit 4: AGL. Bit 5: Magnetometer. Bit 6: Heading. Bit 7: Attitude. Bit 8: Gyro bias. Bit 9: Accelerometer bias. Bit 10: Magnetometer bias. Bit 11: Wind. Bit 12-15: Filter mode: aligning, ready, normal, AHRS.
10	NavHealth_1	
11	NovatelStatus	Navigation health information for external GPS or GPS/INS 5 MSB's: Novatel Solution Status 3 LSB's: Novatel INS Status
12	SolutionType	External GPS/INS solution type (Novatel Solution Type)
13	Reserved	
14	RSSI	Receive signal strength indicator for the internal datalink, as a signed 8 bit number in dBm, typically from -71 to -115.
15	VSWR	8-bit unsigned datalink VSWR in units of 0.02. If zero then VSWR is not available.
16	LoopStatus_0	16-bit loop status bit field: 0 = off, 1 = on, 2 = auto Bit 0-1: 1st loop status. Bit 2-3: 2nd loop status. Bit 4-5: 3rd loop status. Bit 6-7: 4th loop status. Bit 8-9: 5th loop status. Bit 10-11: 6th loop status. Bit 12-13: 7th loop status. Bit 14-15: 8th loop status.
17	LoopStatus_1	
18	LoopTelem_0	16-bit loop telemetry status bit field, set if true. Bit 0: 1st loop is less than min limit. Bit 1: 1st loop is more than max limit. Bit 2: 2nd loop is less than min limit. Bit 3: 2nd loop is more than max limit. Bit 4: 3rd loop is less than min limit. Bit 5: 3rd loop is more than max limit. Bit 6: 4th loop is less than min limit. Bit 7: 4th loop is more than max limit. Bit 8: 5th loop is less than min limit. Bit 9: 5th loop is more than max limit. Bit 10: 6th loop is less than min limit. Bit 11: 6th loop is more than max limit. Bit 12: 7th loop is less than min limit. Bit 13: 7th loop is more than max limit.
19	LoopTelem_1	

		Bit 14: 8th loop is less than min limit. Bit 15: 8th loop is more than max limit.
20	Num loops	The number of loops that this controller supports (1-8).
21	GlobalStatus	8-bit Global status Bit 0: Global on. Bit 1-2: 2-bit manual assist mode: • Standard: no manual assistance. • Lateral. • Longitudinal. • All: Lateral and Longitudinal. Bit 3-7: 5-bit autopilot mode. Mode 0 is pre-launch all other modes are controller specific.
22	Actions_1	16-bit action status Bit 0: Reserved Bit 1: Launch action 1 Bit 2: Launch action 2 Bit 3: Drop deployed Bit 4: Lights active Bit 5: Engine kill active Bit 6: Parachute deployed Bit 7: Parachute pending RPM Bit 8: Aerodynamic termination Bit 9-15: Brakes 0 (off) to 100 (full)
23	Actions_2	
24	Failure	Failure bitfield: Bit 0: Flight termination asserted. Bit 1: Deadman output is on. Bit 2: GPS timeout has elapsed. Bit 3: Communications timeout has elapsed. Bit 4: Manual pilot has killed the engine. Bit 5: Autopilot has killed the engine. Bit 6: Operator has killed the engine. Bit 7: Reserved.
25	Reserved	
26	Tracker_0	16-bit tracker status bit field: Bit 0-1: Tracker loop status, off, on, auto. Bit 2-8: Index of waypoint from 0-99. Bit 9-15:Index of waypoint to 0-99.
27	Tracker_1	
28	TrackStatus_0	16-bit track status bit field: Bit 0: Set if the system is orbiting (or hovering). Bit 1-15: ETA to waypoint in seconds, or time remaining in orbit if performing timed orbit. If orbit is untimed this value is zero.
29	TrackStatus_1	
30	RollBias	8-bit signed roll rate bias in 1/1000th radian/s
31	PitchBias	8-bit signed pitch rate bias in 1/1000th radian/s
32	YawBias	8-bit signed yaw rate bias in 1/1000th radian/s
33	X_accelBias	8-bit signed x acceleration bias in 1/100th m/s/s
34	Y_accelBias	8-bit signed y acceleration bias in 1/100th m/s/s
35	Z_accelBias	8-bit signed z acceleration bias in 1/100th m/s/s
36	X_magBias	8-bit signed x magnetic field bias in 1 mGuass
37	Y_magBias	8-bit signed y magnetic field bias in 1 mGuass
38	Z_magBias	8-bit signed z magnetic field bias in 1 mGuass
39	Reserved	
40	HorizStdDev_0	16-bit floating point (see 4.2.1)
41	HorizStdDev_1	Horizontal position standard deviation (meters).

42	VertStdDev_0	16-bit floating point (see 4.2.1) Vertical position standard deviation (meters).
43	VertStdDev_1	
44	StartAlt_0	16-bit unsigned integer altitude of the start of the track segment, in 0.5 meters above 1000 meters below WGS-84. (height = ((Height_0<<8)|Height_1)*0.5)-1000).
45	StartAlt_1	
46	DestAlt_0	16-bit unsigned integer altitude of the destination waypoint, in 0.5 meters above 1000 meters below WGS-84. (height = ((Height_0<<8)|Height_1)*0.5)-1000).
47	DestAlt_1	
48	StartLat_0	24-bit unsigned latitude of the start of the track segment. The 24-bit latitude is formed according to: Lat24 = (Latitude + PI) * (16777216/2PI).
49	StartLat_1	
50	StartLat_2	
51	StartLon_0	24-bit unsigned longitude of the start of the track segment. 24-bit longitude is formed according to: Lon24 = (Longitude + PI) * (16777216/2PI).
52	StartLon_1	
53	StartLon_2	
54	DestLat_0	24-bit unsigned latitude of the destination waypoint. The 24-bit latitude is formed according to: Lat24 = (Latitude + PI) * (16777216/2PI).
55	DestLat_1	
56	DestLat_2	
57	DestLon_0	24-bit unsigned longitude of the destination waypoint. 24-bit longitude is formed according to: Lon24 = (Longitude + PI) * (16777216/2PI).
58	DestLon_1	
59	DestLon_2	
60	Target0_0	16-bit floating point (see 4.2.1) 1st loop target. The interpretation is controller specific.
61	Target0_1	
62	Target1_0	16-bit floating point (see 4.2.1) 2nd loop target. The interpretation is controller specific.
63	Target1_1	
64	Target2_0	16-bit floating point (see 4.2.1) 3rd loop target. The interpretation is controller specific.
65	Target2_1	
66	Target3_0	16-bit floating point (see 4.2.1) 4th loop target. The interpretation is controller specific.
67	Target3_1	
68	Target4_0	16-bit floating point (see 4.2.1) 5th loop target. The interpretation is controller specific.
69	Target4_1	
70	Target5_0	16-bit floating point (see 4.2.1) 6th loop target. The interpretation is controller specific.
71	Target5_1	
72	Target6_0	16-bit floating point (see 4.2.1) 7th loop target. The interpretation is controller specific.
73	Target6_1	
74	Target7_0	16-bit floating point (see 4.2.1) 8th loop target. The interpretation is controller specific.
75	Target7_1	

4.2.3 Command packets

These packets are used to change or request the current system commands.

4.2.3.1 AUTOPILOT_LOOP

The autopilot loop command packet is used to command the settings of individual autopilot loops. The autopilot will echo this packet in response. The loop command change can also be seen when the system status packet is downlinked. Do not use this packet to change the tracker waypoint command.

Table 27. Autopilot Loop Commands

Byte	Name	Meaning
0	Loop	The loop identifier, which is controller specific.

1	Control	The loop control field. Possible values are 0 (off), 1 (on), or 2 (auto). For loops which do no support automatic control the auto selection acts the same as the on selection.
2	Reserved	
3	Reserved	
4	Value_0	The command value of the loop as a 32-bit floating point number. The interpretation of this value depends on the controller and loop identifier.
5	Value_1	
6	Value_2	
7	Value_3	

4.2.3.2 TRACK

This packet is used to command the autopilot to track a new waypoint segment. The segment can be described by a destination waypoint, and its origination waypoint in the flight plan, or by the destination waypoint and the current position of the aircraft. The autopilot responds by echoing the packet.

Table 28. Track command packet

Byte	Name	Meaning
0	To	The waypoint number to track or go to.
1	Goto	If 0 then use the waypoint that proceeds To as the start of the segment. Else use the current position.

4.2.3.3 PRE_LAUNCH_MODE

Send this zero length packet to command the autopilot to prelaunch mode. The autopilot will respond by sending the short SYSTEM_STATUS packet.

4.2.3.4 LAUNCH_NOW

The launch now packet will command the autopilot to initiate launch procedures, if it is currently in pre launch mode. If the vehicle is currently launching than this command will cause the controller to abort the launch process. If the vehicle is flying this command will do nothing. Launch procedures are controller specific. The autopilot will respond to this packet by sending the short SYSTEM_STATUS packet.

4.2.3.5 LAND_NOW

The land now packet will command the autopilot to initiate recovery procedures, if the vehicle is currently flying. Recovery procedures are controller specific. If the vehicle is currently performing a recovery this packet will cause the controller to abort the recovery. Recovery procedures are controller specific. The autopilot will respond to this packet by sending the short SYSTEM_STATUS packet.

4.2.3.6 ABORT

The abort command tells the autopilot to abort whatever it is currently doing. The actual action taken depends upon the controller and its current state.

Table 29. Fixed wing generation 2 controller abort cases.

Controller state	Abort action
Prelaunch	Kill the engine and apply full brakes

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Transition	Kill the engine and go to rollout state.
Liftoff	No action taken.
Climbout	No action taken.
Flying	Go to lost communications flight plan, set airspeed and altitude loops to automatic state.
Landing	Execute a landing go-around, the same as sending the LAND NOW command.
Final Approach	Execute a landing go-around, the same as sending the LAND NOW command.
Short Final	Execute a landing go-around, the same as sending the LAND NOW command.
Touchdown	Execute a landing go-around, the same as sending the LAND NOW command.
Rollout	Kill the engine and apply full brakes.

4.2.3.7 MANUAL_ASSIST_MODE

This packet is used to specify the manual assist mode. The manual assist mode controls what the autopilot does with the manual pilot sticks data when the system is globally in the auto state. The are four different manual assist modes modes: `STANDARD`, `LATERAL`, `LONGITUDINAL`, and `ALL`. The `STANDARD` mode has no manual assist. The specific interpretation is controller specific, however in the `LATERAL` mode the aileron stick position used for manual assist. In the `LONGITUDINAL` mode the elevator stick position is used for manual assist. The `ALL` mode is a combination of the `LATERAL` and `LONGITUDINAL` mode plus the throttle, rudder, and flaps position. This command has no impact on the autopilot mode state, and can be commanded whether the avionics is globally in auto or manual piloting state. The system will respond by sending this packet to reflect the new manual assist mode. The mode can also be seen in the system status packet. To request the current mode send this packet with zero length.

Table 30. Autopilot Mode Command

Byte	Name	Meaning
0	Mode	The mode of operation: 0) MA_STANDARD 1) MA_LATERAL 2) MA_LONGITUDINAL 3) MA_ALL
1	Reserved	

4.2.3.8 ENGINE_KILL

The engine kill command packet is used to engage the engine kill feature of the autopilot. In response the avionics sends the autopilot commands packet. When the engine kill feature is enabled the throttle is held at 0, independent of the autopilot minimum throttle setting.

Table 31. Engine Kill Command

Byte	Name	Meaning
0	Kill	Non zero to engage engine kill, else zero.
1	Reserved	

4.2.3.9 WAYPOINT

The waypoint packet is used to send a new waypoint. The avionics has storage for 100 waypoints. The waypoint packet includes an index value to specify where in the storage list this waypoint belongs. The avionics responds by echoing the packet.

Table 32. Waypoint packet

Byte	Name	Meaning	
0	Lat_0	32-bit signed integer latitude, in milli-arcseconds.	
1	Lat_1		
2	Lat_2		
3	Lat_3		
4	Lon_0	32-bit signed integer longitude, in milli-arcseconds.	
5	Lon_1		
6	Lon_2		
7	Lon_3		
8	Flags1	Bit0	Set to deploy parachute when this waypoint is reached (MSB)
		Bit1	Set to deploy drop when this waypoint is reached
		Bit2	Orbit direction, 0 indicates left turn, 1 indicates right turn
		Bit3	Set to use waypoint as camera target
		Bit4	Set to make this point a landing point. A landing plan must contain one, and only one, waypoint with this bit set.
		Bit5	Set to enable slope control, which will cause the vehicle to fly on the slope between two waypoints, rather than immediately reaching the target altitude.
		Bit6	Set to turn lights on while tracking waypoint
		Bit7	Set to enable pre-turn for this waypoint (LSB)
9	Orbit Radius	Orbit radius, in tens of meters. If zero the system isn't orbiting.	
10	AltHi	16-bit signed altitude of the waypoint in meters above sea level.	
11	AltLo		
12	WindFind	Windfinding by maneuver interval in hundreds of meters. 0 indicates no windfinding.	
13	Orbit Time	Orbit time, in tens of seconds. If zero then the vehicle will orbit indefinitely. Valid range 0-253.	
14	This	Index of this waypoint.	
15	Next	Index of the following waypoint.	
16	User	User defined byte of information stored with the flight plan.	
17	Flags2	Bit0	Set to cause the vehicle to orbit while it is above the target altitude. Orbit radius must be non-zero. (MSB)
		Bit1	Set to cause the vehicle to orbit while it is below the target altitude. Orbit radius must be non-zero.
		Bit2	Set to make the point a hover waypoint (helicopter only).
		Bit3-4	Reserved, set to zero.
		Bit5-7	unsigned AltLSB in units of 0.125 m. These bits are used to improve the altitude resolution. The final altitude of the waypoint is calculated according to Altitude + AltLSB/8.

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4.2.3.10 WAYPOINT_LIST

The waypoint list packet is used to request or delete waypoints, or initiate a block waypoint transfer. If the packet is used for request then the stream responds by sending the requested waypoints. If any of the requested waypoints are not valid then the stream also sends a waypoint list packet containing the currently valid waypoint list. If the packet is used to delete waypoints then the avionics responds by sending an up to date waypoint list after deleting the requested waypoints. Note that waypoints will not be deleted if they are part of the flight plan in use, or part of the lost communications flight plan.

This packet can also be used to initiate a block waypoint transfer. In that case this packet tells the avionics what waypoints to expect. Only when all of the expected waypoints have been received will the avionics transfer them to flight plan storage and echo the waypoints back The block waypoint transfer will remain in effect until all the waypoints are received or until 10 seconds has elapsed since the last waypoint in the block was received.

Table 33. Request waypoint packet

Byte	Name	Meaning
0	0_7	Flag bits for waypoints 0 through 7. MSB is waypoint 0
1	8_15	Flag bits for waypoints 8 through 15. MSB is waypoint 8
2	16_23	Flag bits for waypoints 16 through 23. MSB is waypoint 16
3	24_31	Flag bits for waypoints 24 through 31. MSB is waypoint 24
4	32_39	Flag bits for waypoints 32 through 39. MSB is waypoint 32
5	40_47	Flag bits for waypoints 40 through 47. MSB is waypoint 40
6	48_55	Flag bits for waypoints 48 through 55. MSB is waypoint 48
7	56_63	Flag bits for waypoints 56 through 63. MSB is waypoint 56
8	64_71	Flag bits for waypoints 64 through 71. MSB is waypoint 64
9	72_79	Flag bits for waypoints 72 through 79. MSB is waypoint 72
10	80_87	Flag bits for waypoints 80 through 87. MSB is waypoint 80
11	88_95	Flag bits for waypoints 88 through 95. MSB is waypoint 88
12	96_99	Flag bits for waypoints 96 through 99. MSB is waypoint 96
13	Flag	The flag values are: 0) Request current valid waypoint list (Up); Current valid waypoint list is included (Down). 1) Delete all waypoints in the list (Up). 2) Request all waypoints in the list (Up). 3) Initiate block transfer for listed waypoints (Up).

4.2.3.11 RADIO_TRANSMIT_DISABLE

The radio transmit disable packet is used to disable or re-enable radio transmissions. For the internal MHX radio the radio is actually held in reset and no data can be received. The autopilot will automatically re-enable radio transmission when it changes out of PRE_LAUNCH state. If this packet is used to disable radio transmission than there is no response to the packet.

Table 34. Radio transmit disable packet

Byte	Name	Meaning		
0	Radio_0	Bit	Name	Meaning
1	Radio_1	0 (MSB)-14	Reserved	Reserved for other radios, set to zero

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		15 (LSB)	MHX_Radio	Set non-zero to disable MHX radio transmissions. Set to zero to re-enable transmission.

4.2.3.12 RADIO_SETTINGS

The radio settings packet is used to request or change the internal radio frequency, hopping pattern and output power. Send the packet with zero length to request the current settings. When requesting or changing the radio settings the radio must be taken off line, which will result in a temporary loss of communications. Hence this should not be done during manual control. If the settings are changed using the UHF link then the ground stations settings must be changed to match the avionics to reestablish communications. If communications are not reestablished the avionics will change back to the original settings when ten seconds have elapsed.

Table 35. Radio settings packet

Byte	Name	Meaning
0	Channel	The hopping pattern to use with the MHX radio. Valid settings are 0 to 57. Not valid for coherent frequency radios.
1	Power	The power setting to use with the radio in hundredths of a Watt.
2	Speed	Radio speed setting. Use zero for default speed, 1 for narrow band operation, and 3 for wide band operation. This setting only applies to MHX_x20 radios with dual receiver front end.
3	Type	The type of internal radio. This value is only for downlink packets Defined types are: 0) MHX_910. 900MHz ISM microhard radio. 1) MHX_2400. 2.4GHz ISM microhard radio. 2) MHX_920. Next generation 900MHZ ISM microhard radio. 3) MHX_2420. Next generation 2.4GHz ISM microhard radio. 4) MHX_420. 450 MHz coherent frequency microhard radio. 5) MHX_320. 350 MHz coherent frequency microahrd radio. 6) MHX_1320. 1.3 GHz coherent frequency microhard radio. 7) EXTEND_900 900MHz ISM Maxstream radio.
4	Freq_0	32-bit floating point radio frequency in Megahertz. Not valid for ISM radios.
5	Freq_1	
6	Freq_2	
7	Freq_3	

4.2.3.13 LIGHTS_CMD

The lights command packet is used to enable or disable the lights. This packet will only have an effect if the i/o line setup of the avionics has been configured to operate lights. The status of the lights can be determined from the autopilot commands packet.

Table 36. Lights command packet

Byte	Name	Meaning
0	Enable	1 to turn lights on, zero to turn them off.

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4.2.3.14 DROP_CMD

The drop command packet is used to deploy or retract the drop function. This packet will only have an effect if the i/o line setup of the avionics has been configured for the drop function. The status of the drop function can be determined from the autopilot commands packet.

Table 37. Drop command packet

Byte	Name	Meaning
0	Enable	1 to activate drop function, zero to retract drop function.

4.2.3.15 PARACHUTE_CMD

The parachute command packet is used to deploy or retract a parachute. This packet will only have an effect if the i/o line setup of the avionics has been configured for the parachute function. The status of the parachute function can be determined from the autopilot commands packet.

Table 38. Parachute command packet

Byte	Name	Meaning
0	Enable	1 to deploy parachute, zero to retract parachute.

4.2.3.16 BRAKES_CMD

The brakes command packet is used to actuate the brakes. This packet will only have an effect if the i/o line setup of the avionics has been configured for the brake function. The status of the brake function can be determined from the autopilot commands packet.

Table 39. Brake command packet

Byte	Name	Meaning
0	Brakes_0	Unsigned 16-bit brake value, from 0 to 1000. 1000 is braes fully applied, 0 is brakes fully released.
1	Brakes_1	

4.2.3.17 CREATE_SIMPLE_LANDING

This packet is used to tell the avionics to build a landing flight plan. The landing flight plan contains six waypoints: a five corner plan with the touchdown point in the middle of one of the long legs. The autopilot will reply by sending the six new waypoints. This packet will also set the autoland waypoint in the mission limits. To request the current landing pattern send this packet with zero length. The simple landing packet uses parameter information stored on the aircraft to determine most of the approach parameters such as approach length, climbout length, etc.

Table 40. Landing packet

Byte	Name	Meaning
0	Lat_0	32-bit signed integer latitude of the touchdown point, in milli-arcseconds.
1	Lat_1	
2	Lat_2	
3	Lat_3	
4	Lon_0	32-bit signed integer longitude of the touchdown point, in milli-arcseconds.
5	Lon_1	
6	Lon_2	
7	Lon_3	

8	Alt_0	32-bit signed integer altitude of the touchdown point, in centimeters above sea level (MSL).
9	Alt_1	
10	Alt_2	
11	Alt_3	
12	Heading_0	16-bit signed integer true heading of the final approach from -180 to 180, in hundredths of a degree.
13	Heading_1	
14	Direction	8-bit signed direction, -1 or clockwise, 1 for counter-clockwise.
15	StartIndex	Starting waypoint index to use for the five waypoint landing flight plan.

4.2.3.18 DOUBLET_CMD

The doublet command packet is used to evaluate the aircraft open loop plant dynamics. It enables vehicle designers to apply a control doublet to any surface and see the vehicle response. The autopilot must be in auto mode for this packet to be accepted. The autopilot will perform the doublet maneuver, and buffer the resulting sensor data. The buffered data is downlinked when the doublet maneuver is completed.

The doublet maneuver begins by disabling the lateral or longitudinal half (or both) of the autopilot and deflecting the desired control axis for the pulse time. When the pulse time completes the system then returns the control axis to neutral or to the negative of the deflection command, in which case it waits another pulse time before returning the control axis to neutral. Once the control axis is neutralized the system continues to operate in doublet mode until the doublet duration is expired. When the doublet expires the autopilot is re-enabled.

Table 41. Doublet command

Byte	Name	Meaning	
0	Flags	Bits describing how the doublet is applied.	
		0(MSB)	Set this bit to make the doublet go both positive and negative deflections. Each deflection will last for the pulse time.
		1	Set this bit to disable all autopilot loops during the doublet. If this bit is clear then lateral loops will remain on during a longitudinal doublet and vice versa.
		2-3	Reserved
		4-7(LSB)	Enumerates the axis to be commanded. The axis enumeration is 0 = ROLL, 1 = PITCH, 2 = THROTTLE, 3 = RUDDER, 4 = FLAPS. An out of range axis will cancel a doublet in progress.
1	Duration	Unsigned 8-bit duration of the doublet in seconds.	
2	Pulse_0	Unsigned 16-bit time of the double pulse in milliseconds. The doublet pulse is the amount of time that the control surface will remain deflected. This value is limited to the resolution of the autopilot.	
3	Pulse_1		
4	Center_0	Signed 16-bit center position of the doublet. For throttle this is in units of 0.0001. All other axis are in units of milli-radians. Pass a value which is outside the autopilot limits to make the autopilot use the current integrator output for this loop.	
5	Center_1		
6	Delta_0	Signed 16-bit axis deflection of the doublet. For throttle	

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7	Delta_1	this is in units of 0.0001. All other axis are in units of 0.1 milli-radians. The sum of this value plus the center will be truncated to the autopilot limits.

4.2.3.19 DOUBLET_AP_DATA

This is one of the packets that the autopilot uses to downlink the results of the doublet maneuver. The downlink uses two packet types, one for basic sensor data, which is returned at faster than autopilot rate, and one for data returned at autopilot rate. This packet returns the data that is buffered at autopilot rate. Since there is more data than can fit in a single packet the data are returned in a series of packets. The number of packets depends on the length of the doublet maneuver.

Table 42. Doublet autopilot data

Byte	Name	Meaning
0	SampleIndex_0	Sample index for this packet, which increases by 10 samples for each packet. The time location of the start of this data is the SampeIndex divided by the SampleRate.
1	SampleIndex_1	
2	SampleRate_0	The rate at which the data in this packet are returned, e.g. 20 samples per second.
3	SampleRate_1	
4	TotalSamples_0	The total number of autopilot data samples to be downloaded. Note that the last packet received may have less than 10 samples in it, depending on the total number of samples.
5	TotalSamples_1	
6	LeftRPM_0	16-bit unsigned RPM of the left engine.
7	LeftRPM_1	
8	RightRPM_0	16-bit unsigned RPM of the right engine.
9	RightRPM_1	
10	ROLL_0	16-bit signed estimated Euler roll angle in 0.1 milli-radians.
11	ROLL_1	
12	PITCH_0	16-bit signed estimated Euler pitch angle in 0.1 milli-radians.
13	PITCH_1	
14	YAW_0	16-bit signed estimated Euler yaw angle in 0.1 milli-radians.
15	YAW_1	
16	Aileron_0	16-bit signed aileron output in 0.1 milli-radians. This is the signal prior to going through mixing.
17	Aileron_1	
18	Elevator_0	16-bit signed elevator output in 0.1 milli-radians. This is the signal prior to going through mixing.
19	Elevator_1	
20	Throttle_0	16-bit signed throttle output in units of 0.0001. This is the signal prior to going through mixing.
21	Throttle_1	
22	Rudder_0	16-bit signed rudder output in 0.1 milli-radians. This is the signal prior to going through mixing.
23	Rudder_1	
24	Flap_0	16-bit signed flap output in 0.1 milli-radians. This is the signal prior to going through mixing.
25	Flap_1	
26…205	Samples	20 bytes for each sample of data, following order given in bytes 6-25. 10 samples total per packet.

4.2.3.20 DOUBLET_SENSOR_DATA

This is one of the packets that the autopilot uses to downlink the results of the doublet maneuver. This packet is used to return basic sensor data which is recorded faster than autopilot rate. Since there is more data than can fit in a single packet the data are returned in a series of packets. The number of packets depends on the length of the doublet maneuver.

Table 43. Doublet sensor data

Byte	Name	Meaning
0	SampleIndex_0	Sample index for this packet, which increases by 10 samples for each packet. The time location of the start of this data is the SampeIndex divided by the SampleRate.
1	SampleIndex_1	
2	SampleRate_0	The rate at which the data in this packet are returned, e.g. 100 samples per second.
3	SampleRate_1	
4	TotalSamples_0	The total number of sensor data samples to be downloaded. Note that the last packet received may have less than 10 samples in it, depending on the total number of samples.
5	Total_Samples_1	
6	RollRate_0	16-bit signed roll rate in units of 300°/s per 32768 counts.
7	RollRate_1	
8	PitchRate_0	16-bit signed pitch rate in units of 300°/s per 32768 counts.
9	PitchRate_1	
10	YawRate_0	16-bit signed yaw rate in units of 300°/s per 32768 counts.
11	YawRate_1	
12	DynamicP_0	16-bit signed dynamic pressure reading in units of Pascals.
13	DynamicP_1	
14	StaticP_0	16-bit unsigned static pressure reading in units of 2 Pascals per count.
15	StaticP_1	
16	XAccel_0	16-bit signed X acceleration in units of 100m/s/s per 32768 counts.
17	XAccel_1	
18	YAccel_0	16-bit signed Y acceleration in units of 100m/s/s per 32768 counts.
19	YAccel_1	
20	ZAccel_0	16-bit signed Z acceleration in units of 100m/s/s per 32768 counts.
21	ZAccel_1	
22	AnalogA_0	16-bit unsigned analog sample for Piccolo II. 10 bits per five volts.
23	AnalogA_1	
24	AnalogB_0	16-bit unsigned analog sample for Piccolo II. 10 bits per five volts.
25	AnalogB_1	
26	AnalogC_0	16-bit unsigned analog sample for Piccolo II. 10 bits per five volts.
27	AnalogC_1	
28	AnalogD_0	16-bit unsigned analog sample for Piccolo II. 10 bits per five volts.
29	AnalogD_1	
30-245	Samples	24 bytes for each sample of data, following order given in bytes 6-29. 10 samples total per packet.

4.2.3.21 SYSTEM_RESET

This packet commands the system to go through a reset. It should only be used for test and development.

Table 44. System reset packet

Byte	Name	Meaning
0	Reset_0	32-bit unsigned reset check field. Must be 0x89ABCDEF or the packet will be ignored
1	Reset_1	
2	Reset_2	

3	Reset_3	

4.2.3.22 BANDWIDTH_MODE

This packet changes the bandwidth mode of the communications layer. Send this packet with zero length to request the current bandwidth mode, or send it with one byte to request the bandwidth mode of a specific link.

Table 45. Bandwidth mode packet

Byte	Name	Meaning
0	Link	Link enumeration describing which link this bandwidth mode packet affects. Use 0xFF to indicate the link the packet was received on.
1	Regular	Bit field describing how regular (non-development) packets are transmitted. Bit 0 (MSB): Set for low resolution packets, else high Bit 1-7: Bandwidth mode, 0-6, see Table 23.
2	NavDev	Bit field describing how the navigation filter development packets are transmitted. Bit 0 (MSB): Set to enable nav development packets. Bit 1-7: Bandwidth mode, 0 is slowest.
3	ConDev	Bit field describing how the controller development packets are transmitted. Bit 0 (MSB): Set to enable con development packets. Bit 1-7: Bandwidth mode, 0 is slowest.

4.2.4 System setup packets

These packets are used to change or request the settings of the avionics which are specific to the avionics hardware, the aircraft system, and the mission.

4.2.4.1 CONTROLLER_DATA

When uplinked the controller data packet is used to update controller data. When downlinked it is used to provide a read of the controller data. Controller data are organized in categories. Within in each category multiple 32-bit data elements exist. Each data element has an enumerated DataID. The first data element (DataID zero) in each category is always an integer type and is used for purposes of enumeration or bit field flags. All subsequent data elements are IEEE 754 32-bit floating point numbers. The number of data elements in a packet is determined from the size of the packet. The meaning of each data element is controller specific.

The system will respond with an echo of the packet that contains the updated data. This data may be different than what was sent if the controller decides to amend the data values.

Table 46. Universal controller data

Byte	Name	Meaning
0	ControllerID	The controller ID value
1	ControllerVersion	The version of the controller
2	Category	The data category
3	DataID	The starting data ID

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4-7	Word 0	The 32-bit data word which corresponds to the DataID element
8-11	Word 1	The next data word which corresponds to DataID+1
…		
n+4-n+7	Word n	The nth data word which corresponds to DataID+n

4.2.4.2 CONTROLLER_DATA_REQUEST

This packet is used to request data from a universal controller.

Table 47. Universal controller data

Byte	Name	Meaning
0	ControllerID	The controller ID value
1	ControllerVersion	The version of the controller
2	Category	The data category
3	DataID	The starting data ID
4	NumData	The number of data elements to request

4.2.4.3 CONTROLLER_DATA_DEFAULT

This packet is used to request the controller to set some data to default values. The data must reside in a single category of the controller.

Table 48. Universal controller data default

Byte	Name	Meaning
0	ControllerID	The controller ID value
1	ControllerVersion	The version of the controller
2	Category	The data category
3	DataID	The starting data ID
4	NumData	The number of data elements to default

4.2.4.4 SET_FUEL_LEVEL

This packet is used to set the current fuel (or battery charge) level. The system may or may not accept this packet based upon it current state or setup. The resulting fuel level is visible in the telemetry packet.

Table 49. Set fuel level

Byte	Name	Meaning
0	Electric	Set to 1 to indicate that this data are for an electric engine, else fuel engine.
1	Reserved	Set to zero.
2	Reserved	Set to zero.
3	Reserved	Set to zero.
4	Fuel_0	32-bit IEEE 754 floating point fuel level. For electric engines this number is given in Watt-Hours. For fuel engines this number is kilograms of fuel.
5	Fuel_1	
6	Fuel_2	
7	Fuel_3	

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4.2.4.5 THROTTLE_TRIM

This packet is used to set the trim value of just the throttle loop. The autopilot responds by echoing this packet.

Table 50. Autopilot trim settings

Byte	Name	Meaning
0	Throttle_0	16-bit signed throttle trim in units of 0.001.
1	Throttle_1	

4.2.4.6 SURFACE_TABLE

The surface table packet is used to setup the calibration curve for a single control surface. It should only be sent during the initial configuration process. The autopilot stream responds by echoing the packet. To request this packet, send a surface table packet whose size is 1, and the first byte is the index of the desired surface.

If you want to change just the type of the actuator, which actually changing calibration data, send the packet with two bytes, the surface index and the actuator type. The autopilot will respond with the entire control surface packet.

Table 51. Surface table

Byte	Name	Meaning
0	SurfaceIndex	The surface for which this calibration applies, 0-9.
1	Type	The function of the actuator, which is controller specific. Zero disables the actuator.
2	Angle0Hi	The 16-bit signed surface angle of the first point of the table in 1/10000th.
3	Angle0Lo	
4	Width0Hi	The 16-bit unsigned pulse width in microseconds which yields the angle given above.
5	Width0Lo	
6	Angle1Hi	The 16-bit signed surface angle of the next point of the table in 1/10000th.
7	Angle1Lo	
8	Width1Hi	The 16-bit unsigned pulse width in microseconds which yields the angle given above.
9	Width1Lo	
10-37	…	
38	Angle9Hi	The 16-bit signed surface angle of the tenth point of the table in 1/10000th.
39	Angle9Lo	
40	Width9Hi	The 16-bit unsigned pulse width in microseconds which yields the angle given above.
41	Width9Lo	

4.2.4.7 SURFACE_TEST

The surface test packet is used to drive a surface to a specified test position. This packet is used during configuration for calibration purposes. The surface test will be maintained for 60 seconds. The surface test feature is only available when in autopilot mode, i.e. manual control must not be selected.

Table 52. Surface test

Byte	Name	Meaning
0	AngleHi	The 16-bit signed surface angle to drive the surface to,

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1	AngleLo	using the current surface calibration table, in units of milliradians. If absolute value of this is greater than 3.142(π) then the angle test mode is disabled.
2	WidthHi	The 16-bit unsigned pulse width in microseconds which should be applied to the surface in question. If this value is outside the range of 500 to 2500 then pulse width test mode is disabled.
3	WidthLo	
4	SurfaceIndex	The surface being tested, 0-9. If this value is out of range normal control surface actuation is resumed.
5	Frequency	The 8-but unsigned frequency of oscillation in units of 0.1Hz. If zero then the frequency test mode is disabled.
6	DeviationHi	The 16-bit unsigned surface angle deviation from the Angle center point in milliradians. This is used for the frequency test. The surface will be commanded to move in a sinusoid, plus and minus the deviation amount.
7	Deviationlo	

4.2.4.8 SENSOR_ORIENTATION

The sensor orientation packet is used to request or change the avionics installation orientation angles, and the distance from the autopilot IMU to GPS antenna. If the packet is used for request then its size should be zero. Each component of the packet is a 32-bit floating point number in big endian format. Since Piccolo is outfitted with rate and acceleration sensors on all three axis it can be installed in any orientation. The vehicle coordinate system follows the standard aerospace convention: The x-axis points through the nose of the aircraft, the y-axis points through the right wing, and the z-axis points down. The sensor data are sampled and converted in avionics coordinates and then rotated to vehicle coordinates according to the three Euler angles.

The orientation packet includes the three Euler angles which give the rotation *from* the avionics axis *to* the vehicle axis. The Euler rotations always follow the same order: 1) Rotate about the Z axis (Yaw), 2) Rotate about the new Y axis (Pitch), 3) Rotate about the new X axis (Roll).

Table 53. Sensor orientation packet

Byte	Name	Meaning
0-3	Roll	Third Euler angle, in radians.
4-7	Pitch	Second Euler angle, in radians.
8-11	Yaw	First Euler angle, in radians.
12-15	X ant	The X distance from the avionics IMU to the GPS antenna in meters, positive if the GPS antenna is in front of the IMU.
16-19	Y ant	The Y distance from the avionics IMU to the GPS antenna in meters, positive if the GPS antenna is right of the IMU.
20-24	Z ant	The Z distance from the avionics IMU to the GPS antenna in meters, positive if the GPS antenna is below the IMU.

4.2.4.9 AIR_DATA_ZERO

The air data zero packet is used to zero the dynamic pressure and the barometric pressure sensors. When the packet is received the avionics will adjust the pressure sensor offsets in order to remove any bias. The avionics does not respond to the air data zero packet. The effect of the packet can be seen in the telemetry data. Note that this packet *must not* be sent while the aircraft is flying.

Since the barometric pressure sensor is always under the influence of the atmosphere the zeroing process actually compares the barometer output to the altitude passed in sensor zero message. In order to correctly set the barometer offset the altimeter base pressure must already be correctly set. Note that if values less than –500,0000 centimeter is sent for the current altitude the barometer offset adjustment is not made.

Table 54. Sensor zero packet

Byte	Name	Meaning
0	ALT_0	32-bit signed integer barometric altitude, in centimeters above sea level. Send values less than -500,000 cm (-5000 m) to skip adjustment of the altitude offset.
1	ALT_1	
2	ALT_2	
3	ALT_3	

4.2.4.10 ALTIMETER_SETTING

The altimeter base pressure packet is used to tell the avionics what the local *sea level* pressure is. This value is used to compute the barometric altitude from the barometric pressure. The avionics responds by sending the altimeter base pressure packet. Note that if this packet is sent with size zero the avionics simply sends the current altimeter setting.

Table 55. Altimeter base pressure packet

Byte	Name	Meaning	
0	StaticP_0	32-bit unsigned altimeter base pressure in Pascals	
1	StaticP_1		
2	StaticP_2		
3	StaticP_3		
4	Flags	Flags information	
		Bit 0	Set this bit to automatically update the altimeter setting using GPS data.
		Bit 1	Set this bit to automatically update the altimeter using DGPS data.
		Bit 2-7	Reserved
5	Reserved		

4.2.4.11 SYSTEM_VERSION

This packet returns system version information. The avionics sends this packet whenever it receives a system version packet of any length. Use this packet to determine the type and version of the controller running in the autopilot.

Table 56. System version packet

Byte	Name	Meaning
0	Major	Major software version number.
1	Minor	Minor software version number.
2	Sub	Sub software version number.
3	Released	Non-zero if software is released, else software is test version
4	SoftYear_0	16-bit unsigned year of the software release
5	SoftYear_1	
6	SoftMonth	Month of the software release, 1-12
7	SoftDay	Day of the software release, 1-31

8	BoardSN_0	Unsigned 32-bit board serial number. The sixteen least significant bits are the network address.
9	BoardSN_1	
10	BoardSN_2	
11	BoardSN_3	
12	BoardRev_0	Unsigned 32-bit board revision number.
13	BoardRev_1	
14	BoardRev_2	
15	BoardRev_3	
16	BoardConfig_0	Unsigned 16-bit board configuration code.
17	BoardConfig_1	
18	Controller	8 bit controller identifier: 0) Legacy fixed wing 1) Neural net helicopter 2) 2nd generation fixed wing 3) PID helicopter
19	Con Version	8-bit controller version information
20	BoardYear_0	16-bit unsigned year of the board fabrication
21	BoardYear_1	
22	BoardMonth	Month of the board fabrication, 1-12
23	BoardDay	Day of the board fabrication, 1-31

4.2.4.12 *MISSION_LIMITS*

Use this packet to set or request limits placed on the current mission. Send this packet with zero length to request the current mission limits. When sending this packet to the avionics the status bits are not used.

Table 57. Mission limits packet

<table>
<tr><th>Byte</th><th>Name</th><th colspan="3">Meaning</th></tr>
<tr><td>0</td><td>CommTimeout_0</td><td colspan="3" rowspan="4">32-bit unsigned number of milliseconds that the avionics will wait after the last valid communications packet is received before it takes lost comm action.</td></tr>
<tr><td>1</td><td>CommTimeout_1</td></tr>
<tr><td>2</td><td>CommTimeout_2</td></tr>
<tr><td>3</td><td>CommTimeout_3</td></tr>
<tr><td>4</td><td>PilotTimeout_0</td><td colspan="3" rowspan="4">32-bit unsigned number of milliseconds that the avionics will wait after the last valid pilot in the loop packet is received before it turns the autopilot on.</td></tr>
<tr><td>5</td><td>PilotTimeout_1</td></tr>
<tr><td>6</td><td>PilotTimeout_2</td></tr>
<tr><td>7</td><td>PilotTimeout_3</td></tr>
<tr><td>8</td><td>LostCommWaypoint</td><td colspan="3">The waypoint that identifies the lost communications flight plan. If the lost comm Waypoint is invalid (i.e. 0xFF) then the lost comm. flight plan will not be used.</td></tr>
<tr><td rowspan="6">9</td><td rowspan="6">Failure_0</td><td colspan="3">Failure bitfield, status and control bits</td></tr>
<tr><td>Bit0 (MSB)</td><td>status</td><td>Set if the deadman output is on.</td></tr>
<tr><td>Bit1</td><td>status</td><td>Set if flight termination is asserted.</td></tr>
<tr><td>Bit2</td><td>status</td><td>Set if GPS timeout has elapsed.</td></tr>
<tr><td>Bit3</td><td>status</td><td>Set if communications timeout has elapsed.</td></tr>
<tr><td>Bit4</td><td>control</td><td>Set if flight termination causes parachute deployment.</td></tr>
</table>

		Bit5	control	Set if flight termination is asserted when BOTH the GPS and the communications timeouts elapse.
		Bit6	control	Set if flight termination is asserted when the GPS timeouts elapse.
		Bit7	control	Set if flight termination is asserted when the communications timeouts elapse.
10	Failure_1	Bit8	status	Set if aerodynamic termination is active.
		Bit9	control	Set if assertion of flight termination causes aerodynamic termination.
		Bit10	control	Set if assertion of flight termination causes the deadman output to be dropped.
		Bit11	status	Set if the manual pilot has killed the engine.
		Bit12	status	Set if the autopilot has killed the engine.
		Bit13	status	Set if failure assertion has killed the engine.
		Bit14	control	Set to drop the deadman if the engine is killed.
		Bit15 (LSB)	control	Set if assertion of flight termination causes the engine to be killed.
11	AutolandWaypoint	The waypoint that identifies the start of the flight plan to use for autoland. This is the go-around waypoint, i.e. the waypoint that follows the touchdown point.		
12	GPSTimeout_0	32-bit unsigned number of milliseconds that the avionics will wait after the last valid GPS report before it considers the GPS to be failed.		
13	GPSTimeout_1			
14	GPSTimeout_2			
15	GPSTimeout_3			
16	AltitudeMin_0	16-bit signed minimum altitude command that the avionics will accept in meters.		
17	AltitudeMin_1			
18	AltitudeMax_0	16-bit signed maximum altitude command that the avionics will accept in meters.		
19	AltitudeMax_1			

4.2.4.13 EXTERNAL_SERIAL_SETUP

This packet is used to setup the external serial ports on Piccolo. There are five external serial ports on Piccolo II and two external serial ports on other versions of Piccolo. Send the packet with zero length to request the current settings. COM2 can run at 115200 bits per second, all other ports are limited to 57,600 or less.

Table 58. External serial setup

Byte	Name	Meaning
0	COM1 baud rate	This byte selects the baud rate of COM1 in units of 1200 bits per second. 0xFF for do not change; greater than 96 (115200) to disable the port.

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1	COM2 baud rate	This byte selects the baud rate of COM2 in units of 1200 bits per second. Send 0xFF for do not change.
2	COM1 protocol	This byte selects the communications protocol of COM1, see Table 59. Send 0xFF for do not change.
3	COM2 protocol	This byte selects the communications protocol of COM2, see Table 59. Send 0xFF for do not change.
4	COM3 baud rate	This byte selects the baud rate of COM3 in units of 1200 bits per second. 0xFF for do not change; greater than 96 (115200) to disable the port.
5	COM3 protocol	This byte selects the communications protocol of COM3, see Table 59. Send 0xFF for do not change.
6	COM4 baud rate	This byte selects the baud rate of COM4 in units of 1200 bits per second. 0xFF for do not change; greater than 96 (115200) to disable the port.
7	COM4 protocol	This byte selects the communications protocol of COM4, see Table 59. Send 0xFF for do not change.
8	COM5 baud rate	This byte selects the baud rate of COM5 in units of 1200 bits per second. 0xFF for do not change; greater than 96 (115200) to disable the port.
9	COM5 protocol	This byte selects the communications protocol of COM5, see Table 59. Send 0xFF for do not change.

Table 59. Supported serial protocols.

#	Protocol meaning
0	Default protocol, port specific.
1	Standard piccolo communications half duplex.
2	Standard piccolo communications full duplex.
3	Payload stream transfer (default function).
4	NMEA output messages: GPRMC, GPGGA
5	Microair transponder protocol.
6	Payload2 stream transfer.
7	Honeywell HMR2300 magnetometer.
8	Reserved.
9	Reserved.
10	Gimbal protocol.
11	Novatel SPAN protocol.
12	Reserved.
13	Novatel GPS protocol.
14	Piccolo communications over Iridium
15	Iridium IO support (DTR, CD). This protocol cannot be used on COM2

Table 60. Serial ports pins and default functions.

Port	Pins	Default behavior
COM1	33(Rx) and 34(Tx) on 44 pin connector; or 26(Rx) and 27(Tx) on PiccoloLT 37 pin connector	Transparent pass through of payload stream (3)
COM2	31(Rx) and 32(Tx) on 44 pin connector; or 6(Rx) and 7(Tx) on PiccoloLT 37 pin connector	Piccolo communications full duplex (2), also used for firmware update.
COM3	2(Rx) and 3(Tx) on 25 pin Piccolo II connector.	Transparent pass through of payload2 stream (6)

COM4	6(Rx) and 7(Tx) on 25 pin Piccolo II connector.	Piccolo communications over Iridium (14)
COM5	4(Rx) and 5(Tx) on 25 pin Piccolo II connector.	Iridium IO support (15)

4.2.4.14 EXTERNAL_IO_SETUP

This packet is used to setup the I/O lines on the main external connector. Each I/O line has a basic function already assigned to it. This packet can be used to change that function. Send this packet with only one byte to request the I/O line setup data. The one byte specifies the signal whose setup should be returned. If the signal is out of range then the setup for all of the I/O lines is returned.

Table 61. I/O line setup packet

Byte	Name	Meaning	
0	Signal	This byte describes which external I/O line is being addressed. The enumeration is as follows:	
		0	TPU_A[0]; pin 39 on Piccolo connector
		1	TPU_A[1]; pin 38 on Piccolo connector
		2	TPU_A[2]; pin 37 on Piccolo connector
		3	TPU_A[3]; pin 36 on Piccolo connector
		4	TPU_A[4]; pin 35 on Piccolo connector
		5	TPU_B[2]; pin 5 on Piccolo connector
		6	TPU_B[3]; pin 20 on Piccolo connector
		7	PWMSM[0]; pin 44 on Piccolo connector
		8	PWMSM[1]; pin 43 on Piccolo connector
		9	PWMSM[2]; pin 42 on Piccolo connector
		10	PWMSM[3]; pin 41 on Piccolo connector
		11	PWMSM[4]; pin 40 on Piccolo connector
		12	TPU_B[8]; pin 21 on Piccolo II daughterboard connector
		13	TPU_B[9]; pin 19 on Piccolo II daughterboard connector
		14	TPU_B[10]; pin 17 on Piccolo II daughterboard connector
		15	TPU_B[11]; pin 15 on Piccolo II daughterboard connector
		16	QADC_B_AN0; pin 12 on Piccolo II daughterboard connector
		17	QADC_B_AN1; pin 11 on Piccolo II daughterboard connector
		18	QADC_B_AN2; pin 10 on Piccolo II daughterboard connector
		19	QADC_B_AN3; pin 9 on Piccolo II daughterboard connector
1	Mode	This byte describes the mode in which the pin will be operated. The mode is interpreted differently if the the line is digital (0-15) or analog (16-19).	
		Digital line modes	
		0	Default; pin operates in its original function
		1	Discrete out; pin is used as a discrete output which can be driven high or low.
		2	Discrete in; pin is used as a discrete input; only valid for TPU pins.

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		3	Pulse/Period out; pin is used to generate a repeating square wave with specifiable period and high time.
		4	Inverted Pulse/Period out; pin is used to generate a repeating square wave with specifiable period and low time.
		5	Pulse in; pin measures the time between the rising and falling edge of the signal for a specifiable number of input periods; only valid for the TPU pins.
		6	Inverted Pulse in; pin measures the time between the falling and rising edge of the signal for a specifiable number of input periods; only valid for the TPU pins.
		7	Period in; pin measures the time between rising edges of the signal for a specifiable number of input periods; only valid for the TPU pins.
		8	Inverted Period in; pin measures the time between falling edges of the signal for a specifiable number of input periods; only valid for the TPU pins.
		9	Lights; pin is used to actuate the lights command
		10	Parachute servo; pin is used to actuate a servo controlled parachute.
		11	Parachute discrete; pin is used to actuate a discrete IO controlled parachute.
		12	Drop servo; pin is used to actuate a servo controlled drop function.
		13	Drop discrete; pin is used to actuate a discrete IO controlled drop function.
		14	Brakes servo; pin is used to actuate a servo controlled brakes function.
		15	Brake discrete; pin is used to actuate a discrete IO controlled brakes function.
		16	AGL Trigger; pin is used to trigger an AGL sonic altimeter reading.
		17	AGL Sense; pin is used to sense an AGL sonic altimeter reading.
		18	AGL Blank inhibit; pin is used to control the AGL blank inhibit function.
		19	Parachute servo engine on; save as parachute servo but the engine remains running when this mode is used.
		20	Parachute discrete engine on; save as parachute discrete but the engine remains running when this mode is used.
		21	Luanch sense; pin is used to inhibit the autopilot going from prelaunch to flying mode. Used for situations where the airspeed may be high before the vehicle is launched.
		22	Iridium power control; pin is used to control power to an iridium satellite modem.
		Analog line modes	
		0	Default mode; the analog sample is returned in millivolts.
		1	Raw input mode; the raw 10-bit analog to digital conversion is returned in the analog sample packet

		2 — Scaled mode; a converted sample is returned in the analog sample packet.
2	SampleTime	The period at which to sample the pin and send the results out the datalink. Only applies if the pin is set for one of the input modes. The value is specified in units of 0.1 seconds. Note that this value applies to all of the pins configured for input.
3	Reserved	
4	Parameter1_0	32-bit number representing the first parameter describing the operation of the pin. The meaning of the parameter depends on the mode of operation. The meaning for the digital modes are: • Discrete out: nonzero parameter1 sets the pin high, else low. • Pulse/Period out: The period of the output rectangle wave in nanoseconds. • Pulse/Period in: Number of input periods over which to accumulate the signal, max 255. • Lights. Parameter defines the state of the IO line when the lights are off. • Parachute servo. Parameter defines the pulse width (in nanosecodns) sent to the parachute servo when the parachute is not deployed. • Parachute discrete. Parameter defines the state of the output line when the parachute is not deployed. • Drop servo. Parameter defines the pulse width (in nanosecodns) sent to the drop servo when the drop function is not actuated. • Drop discrete. Parameter defines the state of the output line when the drop function is not actuated. • Brakes servo. Parameter defines the pulse width (in nanosecodns) sent to the brake servo when the brake function is not actuated. • Brake discrete. Parameter defines the state of the output line when the brake function is not actuated. • Launch sense. Parameter defines the state of the IO line needed to hold the system in prelaunch. The meaning for the analog modes are: • Scaled mode. Parameter 1 is the sensor offset in ADC counts
5	Parameter1_1	
6	Parameter1_2	
7	Parameter1_3	
8	Parameter2_0	32-bit number representing the second parameter describing the operation of the pin. The meaning of the parameter depends on the mode of operation. The meaning for the
9	Parameter2_1	
10	Parameter2_2	

11	Parameter2_3	digital modes are: • Pulse/Period out: Pulse width of the output rectangle wave in nanoseconds. • Parachute servo. Parameter defines the pulse width (in nanosecodns) sent to the parachute servo when the parachute is deployed. • Drop servo. Parameter defines the pulse width (in nanosecodns) sent to the drop servo when the drop function is actuated. • Brakes servo. Parameter defines the pulse width (in nanosecodns) sent to the brake servo when the brake function is actuated. The meaning for the analog modes are: • Scaled mode. Parameter 2 is the sensor scale factor millionths of output units per ADC count.

4.2.4.15 EXTERNAL_IO_SAMPLE

This packet is used to send the I/O line samples back from the avionics down the datalink. It is sent at the rate specified in the I/O line setup packet. The packet contains samples for all 16 digital lines.

Table 62. External IO sample packet

Byte	Name	Meaning
0	Sample1_0	The sample for the TPU_A[0]. The meaning of the sample depends on the mode of the I/O line: • Discrete in; nonzero if the line is high, else zero. • Pulse/Period in; the number of nanoseconds in the pulse or period measured. If the measurement is made over multiple periods the sample is averaged by the number of periods.
1	Sample1_1	
2	Sample1_2	
3	Sample1_3	
4-63	Sample2-16	The remaining samples for all the digital lines

4.2.4.16 EXTERNAL_ADC_SAMPLE

This packet is used to send the analog line samples back from the Piccolo II avionics down the datalink. It is sent at the rate specified in the I/O line setup packet. The packet contains samples for all 4 analog lines.

Table 63. External ADC sample packet

Byte	Name	Meaning
0	Sample1_0	32-bit single precision sample from the first analog line. Interpretation depends on
1	Sample1_1	
2	Sample1_2	
3	Sample1_3	
4-15	Sample2-4	The remaining samples for all the analog lines.

4.2.4.17 MAG_CALIBRATION

The magnetometer calibration packet is used to set or request the magnetometer calibration data. The calibration can be used to affect an offset (hard iron calibration) and a scale factor change for all three axis of the magnetometer. Send the packet with zero length to request the current magnetometer calibration. To perform an auto-calibration send the packet with four bytes set to 0x89ABCDEF. This will start the auto calibration process which takes roughly 20 seconds. When the calibration is finished this packet will be returned with the computed results. Note that the vehicle must be rotated through a complete 360 degree heading change during the auto calibration.

Table 64. Magnetometer calibration packet

Byte	Name	Meaning
0	XhardIron_0	32-bit floating point hard iron error for the x axis in mGauss. This value is subtracted from the magetic field measurement.
1	XhardIron_1	
2	XhardIron_2	
3	XhardIron_3	
4	YhardIron_0	32-bit floating point hard iron error for the y axis in mGauss. This value is subtracted from the magetic field measurement.
5	YhardIron_1	
6	YhardIron_2	
7	YhardIron_3	
8	ZhardIron_0	32-bit floating point hard iron error for the z axis in mGauss. This value is subtracted from the magetic field measurement.
9	ZhardIron_1	
10	ZhardIron_2	
11	ZhardIron_3	
12	XScaleError_0	32-bit floating point x-axis scale error. The magnetic field measurement is corrected according to: Correct = (Raw-HardIron)/(1.0 + ScaleError)
13	XScaleError_1	
14	XScaleError_2	
15	XScaleError_3	
16	YScaleError_0	32-bit floating point y-axis scale error. The magnetic field measurement is corrected according to: Correct = (Raw-HardIron)/(1.0 + ScaleError)
17	YScaleError_1	
18	YScaleError_2	
19	YScaleError_3	
20	ZScaleError_0	32-bit floating point z-axis scale error. The magnetic field measurement is corrected according to: Correct = (Raw-HardIron)/(1.0 + ScaleError)
21	ZScaleError_1	
22	ZScaleError_2	
23	ZScaleError_3	

4.2.4.18 TRANSPONDER_CONTROL

The transponder control packet is sent to set or request the settings of an external transponder. Send this packet with zero length to request the current settings.

Table 65. Transponder control packet

<table>
<tr><td>Byte</td><td>Name</td><td colspan="2">Meaning</td></tr>
<tr><td>0</td><td>Code_0</td><td colspan="2" rowspan="2">Unsigned 16-bit transponder squawk code.</td></tr>
<tr><td>1</td><td>Code_1</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">ModeFlags</td><td colspan="2">Mode and ident bit field</td></tr>
<tr><td>Bit0-3
(MSb)</td><td>4-bit transponder mode: 0) Standby Mode
1) Mode A
2) Mode C</td></tr>
</table>

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		Bit4-6	Reserved
		Bit7 (LSb)	1 to trigger a transponder ident.

4.2.4.19 SET_FUEL_LEVEL

The set fuel level packet is used to specify the fuel level currently in the vehicle. The controller may use this information to calculate fuel remaining and vehicle mass as fuel is burned off. The avionics does not respond to this packet, but the fuel level will be visible in the telemetry data.

Table 66. Set fuel level packet

Byte	Name	Meaning
0	Fuel_0	32-bit floating point fuel level. This number is interpreted as either Kilograms of fuel or W-Hr of battery capacity. The choice of interpretation is left to the controller.
1	Fuel_1	
2	Fuel_2	
3	Fuel_3	

4.2.4.20 SENSOR_ERROR

The sensor error packet is used to specify the error in some of the sensors, including the AGL (above ground level) sensor, the outside air temperature sensors, and the air data pressure sensors. The AGL sensor error is typically caused by the mounting location of the sensor. For example if the sensor is 30 centimeters above the ground while the vehicle is on the ground than the offset will be 30 centimeters. The Temperature rise describes the difference in temperature from the avionics board temperature sensor and the outside air temperature. The pressure correction gives the multiplier applied to the dynamic pressure to account for static pressure port position error. This error is also used to correct barometric pressure errors coming from static pressure port position error.

Table 67. Sensor error packet

Byte	Name	Meaning
0	AGLOffset_0	Signed 16-bit AGL offset in millimeters.
1	AGLOffset_1	
2	TemperatureRise	Signed 8-bit difference between board and outside air temperature [°C]. OAT = BoardTemp-TempRise.
3	PressureCorrection	Unsigned 8-bit pressure correction percent. Q = QRaw*(PressureCorrection/100.0f). Press = PressRaw + (QRaw - Q).

4.2.5 Miscellaneous packets

4.2.5.1 RESET_REPORT

The reset report packet is sent once when the system starts up and is also sent upon request. It includes the cause the last system reset. The reset could be caused by many things: power on, reset line, watchdog timeout, software exception, etc.

Table 68. Reset report packet

Byte	Name	Meaning
0	RSR_0	Unsigned 16-bit reset status word.

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1	RSR_1	Bit0-2: Reserved Bit3: Watchdog reset Bit4-9: Reserved Bit10: Power On Reset Bit11: Rest pin Bit12-14: Reserved Bit15 (LSB): Exception
2	Exception_0	Unsigned 16-bit exception vector offset. This is only valid if the exception bit is set in the RSR.
3	Exception_1	
4	PC_0	The program counter at the time of exception. this is only valid if the exception bit is set in the RSR.
5	PC_1	
6	PC_2	
7	PC_3	
8	MSR_0	Machine state register at the time of exception. This is only valid if the exception bit is set in the RSR.
9	MSR_1	
10	MSR_2	
11	MSR_3	

4.2.5.2 DESCRIPTION
The description packet is used to set or request a parameter description string. The string is 64 bytes long and is intended to house a string of characters that can be used to identify the set of parameters. Send the packet with zero length to request the current description

Table 69. Description packet

Byte	Name	Meaning
0-63	Description	Parameter description string

4.2.5.3 USER_SPACE
The user space packet is used to set or request the data in the user space. The space is 64 bytes long and is intended to allow third party application integrators to store application specific data that stays with the avionics. Send the packet with zero length to request the current user space data.

Table 70. Description packet

Byte	Name	Meaning
0-63	User space	User data

4.2.5.4 RAW_VIBRATION_DATA
This packet contains data for vibration analysis. The avionics samples its data at 1kHz before downconverting the data to the autopilot rate. The 1kHz data are stored in a 1024 sample buffer and can be downlinked on request. Since autopilot packets do not have enough space to hold the entire sample of data multiple packets are required. The full sample requires 16 packets per sensor. Raw vibration data is requested by sending this packet with one byte, which gives the desired sensor index (or an out of range number to request all sensors).

Table 71. Raw vibration data packet

Byte	Name	Meaning

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0	SensorIndex	The index of the sensor whose data this packet contains, 0-7. 0 = Roll rate, 1 = Pitch rate, 2 = Yaw rate, 5 = X acceleration, 6 = Y acceleration, 7 = Z acceleration.
1	Reserved	Will be zero.
2	SampleIndex_0	Sample index for this packet, multiples of 64 from 0 (first) to 15 (last).
3	SampleIndex_1	
4	Sample0_0	0th 16-bit unsigned sensor sample. This is the raw ADC counts referenced to 4.096 Volts.
5	Sample0_1	
6	Sample1_0	1st 16-bit unsigned sensor sample. This is the raw ADC counts referenced to 4.096 Volts.
7	Sample1_1	
…	…	
130	Sample63_0	63th 16-bit unsigned sensor sample. This is the raw ADC counts referenced to 4.096 Volts.
131	Sample63_1	

4.2.5.5 LINK_BRIDGE

This packet is used to allow systems to move data from one Piccolo link to another Piccolo link. In other words this packet is used if a user application connected to the groundside of one datalink would like to send data to another user application connected to the ground side of a different datalink. In this way the autopilot acts like a routing bridge between the two applications. This packet is variable size, up to the maximum autopilot packet size of 255 bytes.

Table 72. Link bridge packet.

Byte	Name	Meaning
0	LinkIndex	When *received* by the autopilot this bytes specifies the index of the communications link that this packet should be forwarded to. The links are: 0) Internal radio link 1) COM2 serial port 2) COM1 serial port 3) COM3 serial port (Piccolo II only) 4) COM4 serial port (Piccolo II only) 5) COM5 serial port When *sent* from the autopilot this byte contains the index of the source link. In this way groundside applications can determine from this byte where the packet originated.
1-255	User Data	User specified data.

4.2.5.6 ERROR_TEXT

This packet is sent by the autopilot to provide a direct error feedback to the user. It is typically sent in response to an erroneous user command. The data in the packet are interpreted as a 8-bit ASCII text string. The string includes the null termination character.

4.3 Universal controller details

The core control logic is defined by the universal controller API. Universal controllers interact with the user and the remainder of the autopilot in the following ways:

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- By defining command loops (up to eight) and targets for each of these loops. The command loops are controlled with the *AUTOPILOT_LOOP* packet given in 4.2.3.1. All controllers support a tracker loop which is not included in these eight loops.
- By defining actuator types which relate controller outputs to actuator outputs. Actuator types are set with the *SURFACE_TABLE* information given in 4.2.4.6.
- By defining controller states. The controller state is visible in the *SYSTEM_STATUS* packet (4.2.2.3). The controller state can be affected by the *PRELAUNCH* (4.2.3.3), *LAUNCH_NOW* (4.2.3.4), and *LAND_NOW* (4.2.3.5) packets.
- By defining categories of data that govern how the controller functions. These categories of data can be queried or changed. Querying universal controller data is done with the *CONTROLLER_DATA_REQUEST* packet given in 4.2.4.2. Changing universal controller data is done with the *CONTROLLER_DATA* packet given in 4.2.4.1. All the data elements in a category are IEEE 754 32-bit floating point numbers, except the first data ID which is always an integer type.

There are currently four controllers:

Table 73. Controller enumerations

ID	Name
0	Legacy fixed wing controller
1	Neural net helicopter controller
2	Fixed wing generation 2 controller
3	PID helicopter controller

4.3.1 Fixed wing generation two controller details

This controller is used for conventional fixed wing aircraft. The latest version of this controller is 2.

4.3.1.1 Fixed wing generation two command loops

The command loops supported by the fixed wing generation two controller are:

Table 74. Fixed wing generation two command loops

ID	Name	Meaning	States
NA	Tracker	Navigation. This loop adjusts the bank angle command, and altitude command, in order to achieve navigation along flight plans.	OFF, ON
0	IAS	Indicated airspeed command [m/s]. This loop adjusts the throttle and elevator to control the indicated air speed.	OFF, ON
1	Altitude	Altitude command [m]. This loop adjust the vertical rate command to control the altitude. In auto state the command for this loop comes from the tracking system.	OFF, ON, AUTO
2	Bank	Bank angle command [rad]. This loop adjusts the ailerons to control the bank angle of the aircraft. In auto state the command for this loop comes from the heading loop or the tracking system. This loop cannot be commanded to go to auto state, instead turn either	ON, AUTO

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		the tracking or heading loops on to force this loop into auto.	
3	Flaps	Flap angle command [rad]. In the ON state this loop sets the flap to the value commanded value. In the AUTO state this loop automatically chooses the flap angle according to landing or takeoff states and adjusts the flap angle as needed to control the energy rate of the vehicle.	OFF, ON, AUTO
4	Heading	Ground track heading command [rad] (0-2Π). This loop adjusts the bank angle command to achieve the desired ground track heading. In auto state the command for this loop comes from the tracking system. This loop cannot be commanded to go to auto state, instead turn the tracking system on to force this loop into auto.	OFF, ON, AUTO
5	VRate	Vertical rate [m/s]. This loop adjusts the throttle and elevator to achieve the desired vertical rate. In auto state the command for this loop comes from the altitude loop. This loop cannot be commanded to go to auto state, instead turn altitude loop on to force this loop into auto.	OFF, ON, AUTO

4.3.1.2 Fixed wing generation two autopilot modes

Table 75. Fixed wing generation two autopilot modes

ID	Name	Meaning	Exit conditions
0	Prelaunch	Non flying “idle” state, the state the autopilot starts in. The throttle is at the prelaunch setting, and the brakes are applied.	Airspeed, User
1	Transition	Catapult launch detected, or user has commanded rolling launch to start. In rolling takeoff the system is tracking the launch flight plan.	Airspeed, Time
2	Liftoff	Rolling launch speed reached, rotation commenced, waiting for positive vertical rate. This state has no meaning for catapult launch.	Altitude rate, Time
3	Climbout	System is flying, wings level commanded, tracker disabled.	Time
4	Flying	Nominal operating state, all systems functional.	User
5	Landing	Tracking a landing flight plan.	Waypoint switch
6	Final approach	Flying down the final approach towards the decision point.	Decision point
7	Short final	The decision point has been reached and the autopilot has decided to proceed to touchdown.	Altitude
8	Touchdown	The flare altitude has been reached and the autopilot is holding vertical rate while looking for ground contact. The engine may be killed.	Airspeed, Z acceleration
9	Rollout	Ground contact has been detected and the	User

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		autopilot is trying to roll straight down the landing plan. Brakes are applied for target deceleration.	

4.3.1.3 Fixed wing generation two data categories

Table 76. Fixed wing generation two controller categories

ID	Name	Meaning
0	LAT_GAINS	Lateral gains, effecting aileron, rudder, and nosegear
1	LON_GAINS	Longitudinal gains effecting elevator and throttle.
2	TRIMS	Trim positions for the autopilot loops.
3	LIMITS	Autopilot limits.
4	VEHICLE	Vehicle description data.
5	MIXING	Mixing rules not covered by the actuator types.
6	LANDING	Settings used for landing
7	LAUNCH	Settings used for launch.

4.3.1.4 Lateral Gains

This is the data category which gives the gains used for lateral control of the vehicle.

Table 77. Fixed wing generation two lateral gains category

ID	Name	Meaning
		Roll Control
0	Reserved	Set to zero.
1	Reserved	Set to zero.
2	Roll error to roll rate command	Gain relating roll angle error [rad] to roll rate command [rad/s]. Increasing this gain increase the available bandwidth of the inner loop lateral control. Do not zero this gain since that will disable lateral control.
3	Roll rate lpf cutoff	Roll rate low pass filter cutoff frequency [Hz]. Zero to disable. This filter can be used to remove high frequency noise on the roll rate signal. Enabling this filter will reduce the available bandwidth on the lateral control loop.
4	Roll rate error to aileron	Gain relating roll rate error [rad/s] to aileron output [rad]. Used to increase the roll damping of the vehicle. Most conventional fixed wing aircraft do not need extra roll damping and this gain can be zero.
5	Roll rate error integral to aileron	Gain relating the integral of roll rate error [[rad/s]*s] to aileron output [rad]. This gain is used to trim errors in the ailerons. Increasing this gain increases the rate at which the autopilot can respond to events that change the aileron trim. Do not zero this gain since that will disable the ability of the autopilot to trim out aileron errors.
6	Reserved	Set to zero.
7	Reserved	Set to zero.
		Yaw Control
8	Yaw rate lpf cutoff	Yaw rate low pass filter cutoff frequency [Hz]. Zero to disable. This filter can be used to remove high frequency noise on the yaw rate signal. Enabling this

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		filter will reduce the available bandwidth of the yaw damper.
9	Yaw rate error to rudder	Gain relating yaw rate error [rad/s] to rudder output [rad]. Used to provide yaw damping. Conventional vehicles with large vertical tails and long tail moment arms typically do not need yaw damping, however short tailed vehicles, or vehicles with excessive dihedral effect usually do need it. Yaw damping is the best way to stop dutch roll.
10	Side force error integral to rudder	Gain relating the integral of side force error [[m/s/s]*s] to rudder output [rad] while flying. Used to provide automatic turn coordination by driving the rudder to the position that zeros the sideforce. If this gain is zero the autopilot will attempt to coordinate the turn using vehicle parameter information. Note that turn coordination is usually not important unless the vehicle has a very long tail moment arm and flies slowly.
	Manual Yaw Control	
11	Reserved	Set to zero.
12	Manual yaw rate error to rudder	Gain relating yaw rate error [rad/s] to rudder output [rad] while under manual control. This can be used to provide yaw damping assistance to a manual pilot.
	Nose gear steering control	
13	Y to Vy scaling power	Velocity scaling term of the Y to Vy gain (below). 0.0 is no scaling. 1.0 is increasing gain in proportion to velocity.
14	Track Y to Vy	Gain relating cross track error [m] to cross track velocity command [m/s] while the vehicle is on the ground.
15	Track Vy error integral to nose gear	Gain relating the integral of the cross track velocity error [[m/s]*s] to the nose gear angle [rad]. Used to find the error in the nose gear while steering on the ground. Setting this gain to zero will prevent the autopilot from finding trim errors in the nose gear.
16	Track Vy error to nose gear	Gain relating the the cross track velocity error [m/s] to the nose gear angle [rad]. Used to steer the aircraft on the ground.
17	Yaw rate to nose gear	Gain relating the yaw rate [rad/s] to the nose gear angle [rad] while rolling on the ground.
18	Vy to nosegear scaling	Velocity scaling term of the nosegear proportional and integral gains. Zero is no scaling. 1.0 is decreasing gain in proportion to velocity.
19	Reserved	Set to zero.
20	Reserved	Set to zero.
	Track Control	
21	Tracker Convergence	Tracker convergence parameter in dimensionless units. Decreasing this number causes the vehicle to try to fly more closely to the track. Making this value too small will cause track oscillations.
22	Heading error to turn rate.	Gain relating heading error [rad] to turn rate [rad/s]. Used to provide the primary steering input from the either the heading controller or the track controller. The available gain depends on the bandwidth of the inner loop lateral controller.

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23	Reserved	Set to zero.
24	Heading error derivative to turn rate.	Gain relating the derivative of heading error [rad] to turn rate [rad/s]. For vehicles with poor inner loop lateral control bandwidth this gain can help reduce track oscillations, otherwise this gain can be zero.
25	Reserved	Set to zero.

4.3.1.5 Longitudinal Gains

This is the data category which gives the gains used for longitudinal control of the vehicle.

Table 78. Fixed wing generation two longitudinal gains category

ID	Name	Meaning
		Total Energy Control
0	Reserved	Set to zero.
1	Reserved	Set to zero.
2	Altitude error to altitude rate command	Gain relating altitude error [m] to altitude rate command [m/s]. Increasing this gain increases how aggressively the autopilot tries to hold altitude. The available gain is limited by the altitude rate controller bandwidth.
3	Altitude rate lpf cutoff	Altitude rate low pass filter cutoff frequency [Hz]. Zero to disable. This filter can be used to limit the bandwidth on the altitude rate command.
4	Throttle Prediction Trust	Ratio (0.0 – 1.0) describing how much to trust the predicted throttle from vehicle parameters. Lower numbers are safer, higher numbers perform better. When prediction trust is 1.0 the throttle will instantly respond to changes in required power, according to power predicted from vehicle parameters. When prediction trust is 0.0 the throttle will only move in response to feedback errors.
5	Energy rate error integral to throttle	Gain relating the integral of energy rate error [[m/s]*s] to throttle. This is the primary gain that moves the throttle and must not be zero. If throttle prediction trust is 1.0 this gain can be fairly weak, since the bulk of the throttle motion is predicted. If the prediction trust is 0.0 this gain must be strong in order to have fast engine response.
6	Energy rate error integral to flap	Gain relating the integral of energy rate error [[m/s]*s] to flap. When the throttle control is saturated, if this gain is nonzero and the flap control loop is in auto mode, the controller will use this gain to adjust the flap position. Flaps are increased (deployed) to increase energy dissipation rate and vice versa.
		Z acceleration control
7	Elevator prediction Trust	Ratio (0.0 – 1.0) describing how much to trust the elevator prediction from vehicle parameters, from 0.0 (no trust) to 1.0 (full trust). Lower numbers are safer, higher numbers perform better. When using high elevator prediction trust values the Z acceleration error integral to elevator must be strong enough to overcome errors in prediction, otherwise the vehicle could diverge due to mis-predicted elevator motion.

8	Z acceleration lpf cutoff	Z acceleration low pass filter cutoff frequency [Hz]. Zero to disable. This filter can be used to remove noise on the z-acceleration rate measurement. Enabling this filter will reduce the vertical rate control bandwidth.
9	Reserved	Set to zero.
10	Z acceleration error integral to elevator	Gain relating the integral of Z acceleration error [[m/s/s]*s] to elevator. This is the primary gain that moves the elevator and must not be zero. In particular this gain must be strong enough to overcome elevator prediction errors. This gain should be as high as practical in order to maximize the bandwidth of the vertical acceleration and vertical rate control.
11	Z acceleration command lpf cutoff	Z acceleration command low pass filter cutoff frequency [Hz]. Zero to disable. Used to reduce the bandwidth the elevator output motion. This is useful for vehicles that have slow elevator actuators.
12	Reserved	Set to zero.
		Airspeed control
13	TAS error to TAS rate command	Gain relating true air speed error [m/s] to true air speed rate command [m/s/s]. Increasing this gain will increase the bandwidth with which the autopilot tries to control airspeed. This gain must not be zero.
14	TAS rate error to Z acceleration command	Gain relating true air speed rate error [m/s/s] to Z acceleration command [m/s/s]. If the vehicle is not changing airspeed at the desired rate this gain causes the flight path trajectory to curve up or down as needed to correct this problem. This gain must not be zero.
15	Reserved	Set to zero.
		Altitude Control
16	Reserved	Set to zero.
17	Fast IAS threshold	The amount that the longitudinal controller is allowed to let the airspeed exceed command before airspeed control takes priority over altitude control. Use a negative value to make airspeed control always have priority.
18	Altitude rate error to Z acceleration command	Gain relating altitude rate error [m/s] to Z acceleration command [m/s/s]. This gain sets the bandwidth with which the vehicle tries to achieve the desired vertical rate. It must not be zero. In most cases this gain must be at least as large as the “Altitude error to altitude rate command”.
19	Reserved	Set to zero.
		Pitch Damper
20	Pitch rate lpf cutoff	pitch rate low pass filter cutoff frequency [Hz]. Zero to disable. This filter can be used to remove noise on the pitch rate measurement. Enabling this filter will reduce the pitch damping bandwidth.
21	Pitch error to elevator	Gain relating pitch angle error [rad] to elevator output [rad]. This gain can be used to stiffen the aircraft in the pitch axis. In most cases this gain can be zero, and should only be used if acceptable longitudinal performance can not be achieved with the

		altitude and airspeed control.
22	Pitch rate error to elevator	Gain relating pitch rate error [rad/s] to elevator output [rad]. Used to add pitch damping to the vehicle. Most aircraft have adequate pitch damping and hence this gain can be zero.
23	Reserved	Set to zero.
	RPM Control	
24	RPM error to RPM rate command	Gain relating RPM error to RPM rate command. If the rpm limiter is enabled this gain controls the bandwidth with which the limiter tries to achieve the RPM command. This gain cannot be zero if the limiter is enabled.
25	RPM rate error integral to throttle	Gain relating the integral of RPM rate error to throttle. If the rpm limiter is enabled this gain finds the throttle required to achieve the desired RPM rate. This gain cannot be zero if the limiter is enabled.
26	Reserved	Set to zero.
	Brakes Control	
27	X acceleration error integral to brakes	Gain relating the integral of X acceleration error [[m/s/s]*s] to brakes output. Used to find the required brakes signal to achieve the desired deceleration on landing rollout. This gain cannot be zero if brakes are being used.
28	Reserved	Set to zero.

4.3.1.6 Trims

This is the data category which gives the trim values for the vehicle. The trims are the initial estimate of the difference between the predicted performance of a loop and the actual performance.

Table 79. Fixed wing generation two trims category

ID	Name	Meaning
	Automatic Trims	
0	Autotrim	Set to one to allow the system to automatically estimate trims for the aileron and elevator in flight and update the trim parameters. The automatic estimate is done both in manual and autopilot control.
	Trims	
1	Reserved	Set to zero.
2	Aileron	Aileron trim angle in [rad].
3	Elevator	Elevator trim angle in [rad].
4	Throttle	Throttle trim. Set this value to one for catapult launch and zero for rolling takeoff launch.
5	Rudder	Rudder trim angle in [rad].
6	Flap	Flap trim angle in [rad].
7	Nosegear	Nose gear trim angle in [rad].
8	Reserved	Set to zero.

4.3.1.7 Limits

This is the data category which gives the limits used by the controller.

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Table 80. Fixed wing generation two limits category

ID	Name	Meaning
Command Limits		
0	Reserved	Set to zero.
1	Reserved	Set to zero.
2	Bank max	Maximum bank angle [rad]. The bank angle may be limited in flight to values less than this based upon the airspeed and mass estimate.
3	Roll rate max	Maximum roll rate [rad/s]. This value controls the maximum rate at which the lateral control loop will roll the vehicle. Use small values to limit the dynamics the system must tolerate and large values to increase aggressiveness during large bank command transients.
4	Reserved	Set to zero.
5	Reserved	Set to zero.
6	IAS Min	Minimum indicated air speed [m/s] at empty weight. This is the minimum command limit applied to the airspeed control loop, and to the acceleration limiter. The controller assumes the vehicle can sustain a load factor of 1.1 at this indicated speed at empty weight. For weights more than empty the minimum speed is increased as needed to maintain the same lift coefficient.
7	IAS Max	Maximum indicated air speed [m/s]. This is the maximum command limit applied to the airspeed control loop.
8	Descent max fraction	Minimum vertical rate as a fraction of true air speed. This is the minimum command limit applied to the vertical rate loop.
9	Climb max fraction	Maximum vertical rate as a fraction of true air speed. This is the maximum command limit applied to the vertical rate loop. For vehicles that are underpowered use smaller climb fractions to prevent the vehicle trying to climb faster than the available power will allow.
10	Load factor Min	Minimum structural load factor in gravities [g]. This value must be less than 1.0. The load factor limit will be enforced by the acceleration command limiter.
11	Load factor Max	Maximum structural load factor in gravities [g]. This value must be more than 1.0. The load factor limit will be enforced by the acceleration command limiter.
12	Reserved	Set to zero.
13	Steering load Max	Maximum lateral acceleration while rolling on the ground in gravities [g]. Currently not used.
14	RPM Min	Minimum RPM, zero to disable min RPM limiter
15	RPM Max	Maximum RPM, zero to disable max RPM limiter
Actuator output limits		
16	Aileron Max	Maximum aileron output [rad]. Must be greater than zero.
17	Reserved	Set to zero.
18	Elevator Min	Minimum elevator output [rad]. Must be less than max.
19	Elevator Max	Maximum elevator output [rad]. Must be more than min.
20	Reserved	Set to zero.
21	Nose gear Max	Maximum nose gear angle [rad].

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22	Rudder Max	Maximum rudder angle [rad].
23	Reserved	Set to zero.
24	Throttle Min	Minimum throttle output (0.0 to Throttle Max). Must be less than throttle max.
25	Throttle Max	Maximum throttle output (Throttle Min to 1.0). Must be greater than minimum throttle output.
26	Throttle rate	Maximum throttle rate [/s]. Must be greater than zero. This value is used to limit the rate at which the throttle moves in order to prevent the controller from stalling the engine due to transient throttle motion. Smaller numbers reduce the throttle controller bandwidth.
27	Reserved	Set to zero.
28	Flap Min	Minimum flap output [rad].
29	Flap Max	Maximum flap output [rad].
30	Flap Rate	Maximum flap rate [rad/s].
31	Reserved	Set to zero.

4.3.1.8 Vehicle Parameters

This is the data category which gives the vehicle parameters used by the controller. In most cases the default gains can be used without modification as long as the vehicle parameters are accurate.

Table 81. Fixed wing generation two vehicle parameters category packet

ID	Name	Meaning
		Geometry
0	Reserved	Set to zero.
1	Reserved	Set to zero.
2	Wing area	Vehicle reference wing area [m^2]. Used to scale calculations involving the aerodynamic coefficients.
3	Wing span	Vehicle reference wing span [m]. Used to scale calculations involving the rolling moment, yawing moment, aileron, or rudder.
4	Vertical tail arm	Distance from the center of gravity to the vertical tail aerodynamic center [m]. This value is used to estimate the rudder required to turn coordination. Set to zero to disable turn coordination.
5	Nose gear steering arm	Distance from the fixed gear to the steerable gear [m]. This value is used (along with speed) to predict how far to turn the nose gear in order to affect a desired vehicle turn rate.
6	Reserved	Set to zero.
		Mass Properties
7	Gross Mass	Mass of the aircraft full of fuel [Kg]. Must be greater than or equal to the empty mass. The aircraft mass is estimated based upon the empty mass and the fuel mass (which varies). The gross mass is used to limit the amount of fuel that the user can indicate is stored in the aircraft. Electric vehicles, or vehicles for which the fuel burn is unpredictable should set the gross mass equal to the empty mass.
8	Empty Mass	Mass of the aircraft with no fuel [Kg].
9	X Inertia	Inertia of the vehicle about the X axis [$Kg\text{-}m^2$].
10	Y Inertia	Inertia of the vehicle about the Y axis [$Kg\text{-}m^2$]. This

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		value is used in the scaling of the pitch rate feedback.
11	Z Inertia	Inertia of the vehicle about the Z axis [Kg-m^2] . This value is used in the scaling of the yaw rate feedback.
12	Reserved	Set to zero.
	Longitudinal Aerodynamics	
13	Elevator power	Change in pitch moment coefficient per change in elevator [/rad]. Increasing elevator angles should produce decreasing pitch moments, hence this number is negative.
14	CL at zero elevator	The lift coefficient of the vehicle when the elevator is at zero. This value is used along with the elevator trim position to estimate where to place the elevator when the control loops turn on.
15	Elevator effectiveness	Steady state change in lift coefficient per change in elevator position [/rad]. This is the primary elevator control power term. Under steady state assumptions, if the aircraft is statically stable, the angle of attack and hence the lift coefficient are assumed to depend linearly on the elevator according to this term and the "CL at zero elevator". The controller uses this number to predict the correct elevator position based upon the acceleration command, and to scale the elevator feedback gains. Reducing this value causes the controller to move the elevator further. This value should always be negative. If the elevator effectiveness varies over the operating envelope of the aircraft than the largest magnitude value should be given. This is typically the value that occurs at high speeds where trim forces are not significant.
16	Reserved	Set to zero.
	Lateral Aerodynamics	
17	Reserved	Set to zero.
18	Aileron effectiveness	Dimensionless roll rate (pb/2V) per change in aileron position [/rad]. This is the primary aileron control power term. Under steady state assumptions, if the roll damping is large and the roll axis inertia is small, the dimensionless roll rate depends only on the aileron angle according to this term. The controller uses this number to predict the correct aileron position, and to scale the aileron feedback gains. Reducing this value causes the controller to move the aileron further. This value should always be greater than zero.
19	Rudder power	Yawing moment coefficient per change in rudder position [/rad]. This is the primary rudder control power term. In combination with the Z-axis inertia this term is used to scale the gains of the yaw damper. Reducing this value cause the controller to move the rudder further.
20	Rudder effectiveness	Change in sideslip per change in rudder position [rad/rad]. In combination with the tail moment arm this number is used to estimate the amount of rudder deflection required to coordinate a turn. It is only used if the side force integral feedback gain is zero. Reducing this value causes the controller to move the rudder more.
21	Sideslip effect	Change in side force coefficient per change in side slip [/rad]. This term is used to scale the side force integral feedback for feedback turn coordination. Reducing this value causes the controller to move the rudder more.

22	Reserved	Set to zero.
		Engine
23	Reserved	Set to zero.
24	Max engine power	Maximum engine power [W]. This number is used to predict the how far to move the throttle in response to the power required computed by the controller. It is assumed that the net power at throttle of 1.0 will be equal to this value. It is also used to scale the throttle feedback gains. Reducing this number causes the controller to move the throttle further.
25	Engine SFC	Engine specific fuel consumption in grams of fuel per hour per kilowatt of power [g/(kW-hr)]. Set this to zero or less than zero to indicate that the aircraft is electric. If this is positive than the controller will combine it with the throttle position, and the max engine power, to estimate the fuel burn rate. The fuel burn rate will be used to debit the mass of the aircraft to account for fuel burned off. The mass will not be allowed to fall before the “empty mass” value.
26	Reserved	Set to zero.
27	Reserved	Set to zero.
		Lift Coefficients
28	CL max	The maximum lift coefficient that the vehicle can sustain. This number is used during the landing to determine how much acceleration can be developed before stalling the vehicle. It is also used to distinquish between loads that are due to aerodynamics/turbulence and loads that are due to ground contact. Finally this number is used to apply a lower limit to the minimum indicated airspeed command limit, such that the dynamic pressure at MinIAS is 1.1 times the dynamic pressure at CL max.
29	CL climb	The lift coefficient at which the vehicle climbs best. This number is used to determine what speed the vehicle should fly when the airspeed control loop is in AUTO and the vehicle is climbing. Must be less than CL implied by the MinIAS.
30	CL cruise	The lift coefficient at which the vehicle cruises best. This number is used to determine what speed the vehicle should fly when the airspeed control loop is in AUTO and the vehicle is cruising. Must be less than CL implied by the MinIAS.
31	Reserved	Set to zero.
32	Reserved	Set to zero.

4.3.1.9 Mixing

This is the data category which gives the mixing rules used by the controller.

Table 82. Fixed wing generation two mixing category

ID	Name	Meaning
0	Reserved	Set to zero.
1	Reserved	Set to zero.
2	Flap to elevator	Change in elevator output per change in flap [rad/rad]. This value should be chosen such that the lift coefficient produced by the vehicle does not change as the flaps are

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		deployed.
3	Aileron to rudder	Change in rudder output per change in aileron output [rad/rad]. This value is used to reduce the effects of adverse yaw. It cannot be used to provide turn coordination.
4	Aileron differential	Aileron differential motion, 1.0 gives only up aileron, -1.0 gives only down aileron. Also used to reduce the effects of adverse yaw.
5	Flaperon ratio	Amount of aileron fed into the flap output. Used to make flaps surfaces provide rolling moment. If this value is nonzero than the "aileron effectiveness" must be changed to account for its effect.
6	Rudder to nose gear	Change in nose gear output per change in rudder output, while under manual control. For vehicles in which the nose gear is on a separate control channel from the rudder this value is used to provide the pilot with the ability to drive the nose gear channel from the rudder stick.
7	Nose gear to rudder	Change in rudder output per change in nose gear output, while under autopilot control. For vehicles in which the nose gear shares the rudder channel this value provides the autopilot the ability to move the nose gear through the rudder channel.
8	Reserved	Set to zero.

4.3.1.10 Landing

This is the data category which gives the parameters used by the controller to land the vehicle.

Table 83. Fixed wing generation two landing category

ID	Name	Meaning
		Landing Type
0	Landing Type	Integer landing type: 0 for wheeled, 1 for belly landing. Belly landing aircraft do not check for premature touchdown while in short final state.
		Pattern
1	Reserved	Set to zero.
2	Slope	Approach glide path angle [rad]. This value must be shallow enough to allow the aircraft to descend but steep enough to allow it to clear obstacles on final approach.
3	Approach time	Time of the approach [s]. The length of the landing approach is calculated by multiplying this by the approach speed.
4	Go around time	Time of the go around [s]. The length of the go around is calculated by multiplying this by the approach speed.
5	Cross time	Time of the crosswind leg [s]. The length of the crosswind leg is calculated by multiplying this by the approach speed.
		Configuration
6	Flap setting	Nominal flap setting to use during the approach [rad]. This is only used if the flaps control loop is in AUTO.
7	Reserved	Set to zero.
8	Speed fraction	Fraction of the minimum indicated air speed to use during the approach. The approach speed is computed by multiplying this by the minimum indicated air speed.

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9	Reserved	Set to zero.
		Decision
10	Y max error	Maximum tolerable lateral error to allow landing to proceed past decision time [m].
11	Z max error	Maximum tolerable altitude error to allow landing to proceed past decision time [m].
12	Max overspeed	Maximum amount that the indicated airspeed can exceed the commanded speed to allow landing to proceed past decision time [m/s].
13	Decision time	Time before projected touchdown at which to make the decision to continue or abort the approach [m].
		Flare
14	Engine kill time	Time before projected touchdown to kill the engine [s]. Use negative time to keep the engine running.
15	Reserved	
16	Sink rate	Target sink rate for the flare maneuver [m/s]. If this value is greater than or equal to zero than the vertical rate command will be set to this value (negative) when the vehicle is below the flare height (i.e. when in touchdown state). If this value is not greater than or equal to zero than the controller will calculate the vertical rate in order to touchdown smoothly at the touchdown altitude.
17	Flare height	Altitude above touchdown at which the flare maneuver begins [m]. Use negative height for no flare landing
18	Reserved	Set to zero.
		Rollout
19	Deceleration command	Desired rate of deceleration (from brakes) after touchdown [m/s/s]. This value must be greater than zero. The controller will modulate the brakes to achieve this deceleration value.
20	Reserved	Set to zero.

4.3.1.11 Launch

This is the data category which gives the parameters used by the controller to launch the vehicle.

Table 84. Fixed wing generation two launch category

ID	Name	Meaning
		Launch Type
0	Launch Type	Integer launch type: 0) Catapult launch. In catapult launch the controller looks for an indicated air speed reading to indicate that the launch has occurred 1) Rolling wheeled launch. In this launch mode the controller advances the throttle to achieve a commanded acceleration and steers the nose gear to keep the vehicle on the track. When the launch speed is reached the rotation elevator is commanded and the controllers looks for the liftoff. 2) Balloon launch. Launch detection is based upon detection of free fall or airspeed. Climbout mode cannot be exited until pitch angle is above -35 degrees. 3) Tube launch. Launch detection is based upon io line or airspeed. Climbout mode will not be reached until

		launch timers have elapsed at which point proceed as in balloon launch.
		Prelaunch
1	Reserved	Set to zero.
2	Prelaunch flaps	Flaps position to use during prelaunch and through the climbout state [rad]. This flap position is only used if the flaps command loop is in AUTO.
3	Prelaunch throttle	Throttle output to use during prelaunch mode. For rolling takeoff vehicles this value should be small. Note that the controller allows the throttle to violate the minimum while in prelaunch. For electric catapult launch vehicles this value should be zero. For gas catapult launch vehicles this value should one.
4	Prelaunch brakes	Brakes output to use during prelaunch mode. In most cases the prelaunch brakes should be on (1.0)
5	Reserved	Set to zero.
		Safety Checks
6	Reserved	Set to zero.
7	Max cross error	Maximum cross track error [m] allowed during a rolling takeoff. If the cross track error exceeds this value the takeoff is aborted.
8	Minimum RPM	Minimum RPM that must be achieved, half a second after throttle reaches full, to allow takeoff to proceed. Setting this value to zero will also disable the acceleration check.
9	Reserved	Set to zero.
		Engine Control
10	Acceleration	Target X acceleration for rolling takeoff [m/s/s]. Set this number based upon how quickly you want the vehicle to accelerate during the takeoff roll.
11	Slow throttle rate	Rate limit applied to the throttle [/s] during the initial acceleration. Set this value to be small so the initial throttle induced transient is low.
12	Fast throttle rate	Rate limit applied to the throttle [/s] after the initial acceleration.
13	Throttle switch speed	Groundspeed [m/s] at which the throttle rate limit switches from slow to fast.
14	Reserved	Set to zero.
		Rotation
15	Reserved	Set to zero.
16	Rotation elevator	Elevator position [rad] to use when launch speed is reached for rolling takeoff. This value is typically strongly negative with respect to the trim elevator so that the vehicle experiences a strong liftoff impulse.
17	Rotation time	The amount of time [s] used to move the elevator to its rotation position. This time is used to keep the liftoff from being too violent.
18	Reserved	Set to zero.
		Speeds and Times
19	Reserved	Set to zero.
20	Climb speed fraction	Fraction of the minimum indicated air speed to use for the climbout section of the launch. This is also the rotation/launch speed for rolling takeoff.
21	Flying speed fraction	Fraction of the minimum indicated air speed to use once the vehicle transitions to flying mode.

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22	Climbout time	Time after climbout is reached before the system switches into flying mode [s]. Minimum 7 seconds.
23	Reserved	Set to zero.
		Action times
24	Action 1 time	Time [s] after launch begins to actuate launch action 1.
25	Action 2 time	Time [s] after launch action 1 to actuate launch action 2.
26	Action 2 time	Time [s] after launch action 2 to actuate launch action 3.
27	Reserved	Set to zero.
28	Reserved	Set to zero.

4.3.2 Helicopter neural net controller details

4.3.2.1 Command Loops

4.3.2.2 Actuator types

4.3.2.3 Controller states

4.3.2.4 Categories

4.3.3 Helicopter PID controller packets

4.3.3.1 Command Loops

4.3.3.2 Actuator types

4.3.3.3 Controller states

4.3.3.4 Categories

4.4 Gimbal stream

The gimbal stream is used to communicate to a camera gimbal system connected to the Piccolo autopilot. The communications format is documented in the document Gimbal Communications.doc

4.5 CAN component

The CAN component of the avionics communications is used for Piccolo specific functions like servo output or simulator data input.

4.5.1 CAN ID fields

In Piccolo CAN communications use version 2.0B of the CAN protocol at 1Mbaud. This version specifies a 29 bit identifier for each CAN frame. Piccolo interprets this 29 bit field in the following way:

Table 85. CAN 2.0B frame identifier.

Bit	Name	Meaning	
0-5 MSB	Group	Message group, the following groups are defined:	
		0	Piccolo group ID
		1	IMU group ID
		2	GPS group ID
		3	Calibration group ID
		4-30	Reserved
		31	PTU group ID
5-12	Message	8 bit message identifier	
13-28 LSB	Address	16 bit device address. 0xFFFF is a broadcast address.	

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4.5.2 CAN input data

For simulation purposes *Piccolo* will accept externally supplied sensor data from a simulation PC. This data arrives over CAN interface 1, using CAN2.0B. The following tables relate the CAN frame ID to the data contained in the frames. All multi-byte values have their most significant byte first and their least significant byte last.

Table 86. Pitot data CAN frame ID 0x1F0D_FFFF

Byte	Name	Meaning
0	DynamicP_0	32-bit IEEE-754 floating point dynamic pressure in Pascals.
1	DynamicP_1	
2	DynamicP_2	
3	DynamicP_3	
4	OAT_0	32-bit IEEE-754 floating point outside air temperature in Celcius.
5	OAT_1	
6	OAT_2	
7	OAT_3	

Table 87. Barometer data CAN frame ID 0x1F0F_FFFF

Byte	Name	Meaning
0	OffsetP_0	32-bit IEEE-754 floating point static pressure offset in Pascals (nominally 0.0).
1	OffsetP_1	
2	OffsetP_2	
3	OffsetP_3	
4	StaticP_0	32-bit IEEE-754 floating point static pressure in Pascals.
5	StaticP_1	
6	StaticP_2	
7	StaticP_3	

Table 88. Pressure, Temperature, Humidity data CAN frame ID 0x1F04_FFFF

Byte	Name	Meaning
0	StaticP_0	16-bit static pressure in units of 10Pa.
1	StaticP_1	
2	Temp_0	16-bit signed temperature in units 0.1C.
3	Temp_1	
4	Humidity_0	Set to zero
5	Humiditt_1	Set to zero
6	Reserved	Set to zero
7	Reserved	Set to zero

Table 89. Gyro CAN frame ID 0x0105_FFFF

Byte	Name	Meaning
0	RollRate_0	16-bit signed body axis roll rate. ±300°/s full scale (i.e. Resolution of 600°/65536).
1	RollRate_1	
2	PitchRate_0	16-bit signed body axis pitch rate. ±300°/s full scale (i.e. Resolution of 600°/65536).
3	PitchRate_1	
4	YawRate_0	16-bit signed body axis yaw rate. ±300°/s full scale (i.e. Resolution of 600°/65536).
5	YawRate_1	

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Table 90. Accelerometer CAN frame ID 0x0106_FFFF

Byte	Name	Meaning
0	XACCEL_0	16-bit signed body x-axis acceleration. ±98 m/s/s full scale. (i.e. Resolution of 196m/s/65536)
1	XACCEL_1	
2	YACCEL_0	16-bit signed body y-axis acceleration. ±98 m/s/s full scale. (i.e. Resolution of 196m/s/65536)
3	YACCEL_1	
4	ZACCEL_0	16-bit signed body z-axis acceleration. ±98 m/s/s full scale. (i.e. Resolution of 196m/s/65536)
5	ZACCEL_1	

Table 91. Timing CAN frame ID 0x0103_FFFF

Byte	Name	Meaning
0	Reserved	Set to zero
1	Reserved	Set to zero
2	Reserved	Set to zero
3	Reserved	Set to zero
4	Reserved	Set to zero
5	Sequence	Increment for each ground of inertial data sent to avionics, roll over after 255

Table 92. Magnetometer CAN frame ID 0x0005_FFFF

Byte	Name	Meaning
0	MagX_0	16-bit signed x-axis magnetic field, in units of 0.1 nT
1	MagX_1	
2	MagY_0	16-bit signed y-axis magnetic field, in units of 0.1 nT
3	MagY_1	
4	MagZ_0	16-bit signed z-axis magnetic field, in units of 0.1 nT
5	MagZ_1	

Table 93. Engine CAN frame ID 0x0006_FFFF

Byte	Name	Meaning
0	LeftRPM_0	16-bit unsigned left engine RPM
1	LeftRPM_1	
2	RightRPM_0	16-bit unsigned right engine RPM
3	RightRPM_1	
4	Time_0	32-bit unsigned time signal from data source. Piccolo will echo this value in can frame 0x0007xxxx.
5	Time_1	
6	Time_2	
7	Time_3	

Table 94. GPS time CAN frame ID 0x0200_FFFF

Byte	Name	Meaning
0	Month	GPS month, 1…12.
1	Day	GPS day, 1…31.
2	Year_0	unsigned 16-bit GPS year.

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3	Year_1	
4	Hours	GPS hours, 0…23.
5	Minutes	GPS minutes, 0…59.
6	Seconds	GPS seconds, 0…59.
7	fSeconds	GPS fractional seconds in hundredths of a second.

Table 95. GPS position CAN frame ID 0x0201_FFFF

Byte	Name	Meaning
0	LAT_0	32-bit signed integer latitude, in milli-arcseconds.
1	LAT_1	
2	LAT_2	
3	LAT_3	
4	LON_0	32-bit signed integer longitude, in milli-arcseconds.
5	LON_1	
6	LON_2	
7	LON_3	

Table 96. GPS altitude CAN frame ID 0x0202_FFFF

Byte	Name	Meaning
0	Height_0	32-bit signed integer GPS height, in centimeters above sea level.
1	Height_1	
2	Height_2	
3	Height_3	

Table 97. GPS velocity CAN frame ID 0x0203_FFFF

Byte	Name	Meaning
0	NVelocity_0	16-bit signed North component of ground speed in centimeters per second.
1	NVelocity_1	
2	EVelocity_0	16-bit signed East component of ground speed in centimeters per second.
3	EVelocity_1	
4	DVelocity_0	16-bit signed Down component of ground speed in centimeters per second.
5	DVelocity_1	

4.5.3 CAN output data

Piccolo automatically outputs the servo commands on the CAN interface. These outputs are available for use by any CAN servos in the vehicle, or by the hardware in the loop simulator. The outputs include both the pulse width for the servo, and the desired surface deflection.

Table 98. Servo output CAN frame ID 0x0000xxxx

Byte	Name	Meaning
0	PULSE1_0	16-bit unsigned number of microseconds of the pulse high time for channel 1.
1	PULSE1_1	
2	ANGLE1_0	16-bit signed surface deflection for channel 1, in 1/10000th radians.
3	ANGLE1_1	
4	PULSE2_0	16-bit unsigned number of microseconds of the pulse high time for channel 2.
5	PULSE2_1	
6	ANGLE2_0	16-bit signed surface deflection for channel 2, in 1/10000th

7	ANGLE2_1	radians.

Table 99. Servo output CAN frame ID 0x0001xxxx

Byte	Name	Meaning
0	PULSE3_0	16-bit unsigned number of microseconds of the pulse high time
1	PULSE3_1	for channel 3.
2	ANGLE3_0	16-bit signed surface deflection for channel 3, in $1/10000^{th}$
3	ANGLE3_1	radians.
4	PULSE4_0	16-bit unsigned number of microseconds of the pulse high time
5	PULSE4_1	for channel 4.
6	ANGLE4_0	16-bit signed surface deflection for channel 4, in $1/10000^{th}$
7	ANGLE4_1	radians.

Table 100. Servo output CAN frame ID 0x0002xxxx

Byte	Name	Meaning
0	PULSE5_0	16-bit unsigned number of microseconds of the pulse high time
1	PULSE5_1	for channel 5.
2	ANGLE5_0	16-bit signed surface deflection for channel 5, in $1/10000^{th}$
3	ANGLE5_1	radians.
4	PULSE6_0	16-bit unsigned number of microseconds of the pulse high time
5	PULSE6_1	for channel 6.
6	ANGLE6_0	16-bit signed surface deflection for channel 6, in $1/10000^{th}$
7	ANGLE6_1	radians.

Table 101. Servo output CAN frame ID 0x0003xxxx

Byte	Name	Meaning
0	PULSE7_0	16-bit unsigned number of microseconds of the pulse high time
1	PULSE7_1	for channel 7.
2	ANGLE7_0	16-bit signed surface deflection for channel 7, in $1/10000^{th}$
3	ANGLE7_1	radians.
4	PULSE8_0	16-bit unsigned number of microseconds of the pulse high time
5	PULSE8_1	for channel 8.
6	ANGLE8_0	16-bit signed surface deflection for channel 8, in $1/10000^{th}$
7	ANGLE8_1	radians.

Table 102. Servo output CAN frame ID 0x0004xxxx

Byte	Name	Meaning
0	PULSE9_0	16-bit unsigned number of microseconds of the pulse high time
1	PULSE9_1	for channel 9.
2	ANGLE9_0	16-bit signed surface deflection for channel 9, in $1/10000^{th}$
3	ANGLE9_1	radians.
4	PULSE10_0	16-bit unsigned number of microseconds of the pulse high time
5	PULSE10_1	for channel 10.
6	ANGLE10_0	16-bit signed surface deflection for channel 10, in $1/10000^{th}$
7	ANGLE10_1	radians.

Table 103. Servo output CAN frame ID 0x0005xxxx

Byte	Name	Meaning
0	PULSE11_0	16-bit unsigned number of microseconds of the pulse high time for channel 11.
1	PULSE11_1	
2	ANGLE11_0	16-bit signed surface deflection for channel 11, in $1/10000^{th}$ radians.
3	ANGLE11_1	
4	PULSE12_0	16-bit unsigned number of microseconds of the pulse high time for channel 12.
5	PULSE12_1	
6	ANGLE12_0	16-bit signed surface deflection for channel 12, in $1/10000^{th}$ radians.
7	ANGLE12_1	

Table 104. Servo output CAN frame ID 0x0023xxxx

Byte	Name	Meaning
0	PULSE13_0	16-bit unsigned number of microseconds of the pulse high time for channel 13.
1	PULSE13_1	
2	ANGLE13_0	16-bit signed surface deflection for channel 13, in $1/10000^{th}$ radians.
3	ANGLE13_1	
4	PULSE14_0	16-bit unsigned number of microseconds of the pulse high time for channel 14.
5	PULSE14_1	
6	ANGLE14_0	16-bit signed surface deflection for channel 14, in $1/10000^{th}$ radians.
7	ANGLE14_1	

Table 105. Servo output CAN frame ID 0x0024xxxx

Byte	Name	Meaning
0	PULSE15_0	16-bit unsigned number of microseconds of the pulse high time for channel 15.
1	PULSE15_1	
2	ANGLE15_0	16-bit signed surface deflection for channel 15, in $1/10000^{th}$ radians.
3	ANGLE15_1	
4	PULSE16_0	16-bit unsigned number of microseconds of the pulse high time for channel 16.
5	PULSE16_1	
6	ANGLE16_0	16-bit signed surface deflection for channel 16, in $1/10000^{th}$ radians.
7	ANGLE16_1	

Piccolo also outputs a time sync and configuration message in response to the engine input data from the simulator.

Table 106. Configuration output CAN frame ID 0x0007xxxx

Byte	Name	Meaning
0	Time_0	32-bit time reference value that was received in message 0x0006xxxx. This can be used to estimate the round trip data latency of the messages.
1	Time_1	
2	Time_2	
3	Time_3	
4	Config_0	32-bit config word used to describe the hardware and software configuration of the avionics.
5	Config_1	
6	Config_2	
7	Config_3	