



CubeLab Interface Control Document (ICD)

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Revision History

Rev	Date	Details
1.0	Nov-1-2016	Document Created. Initial Release.
1.1	Jan-3-2017	Major Revision to Sections 3 & 4.
2.0	Jun-28-2017	Major Revisions to Sections 2 & 3. Added Section 5.
2.1	Jan-29-2019	Updated document to current CubeLab standards

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1 Document Scope

The CubeLab Interface Control Document (ICD) lists the requirements and interfaces between individual CubeLab Modules and Payload Cards to be operated within TangoLab facilities. The TangoLab (TL) facilities are reconfigurable general research platforms designed for microgravity research and pilot manufacturing aboard the International Space Station (ISS). Experiments are housed within CubeLabs specific to their requirements. TLs are designed to hold 21 CubeLab Units (U), in a variety of configurations, split among three payload cards. Once aboard the ISS, customers can monitor their experimental data throughout the course of the mission. This high-throughput, reconfigurable and automated architecture allows for the scalable and affordable use of microgravity.

1.1 Revision History

This ICD covers the Payload Card and CubeLab designs used since the Space CRS-16 mission.

2 TangoLab Process Flow

The TangoLab facility (Figure 1 – Bottom) uses a Payload Card architecture (Figure 1 – Top Right) allowing for rapid iteration and configurability of individual CubeLab modules (Figure 1 – Top Left) over a variety of use cases.

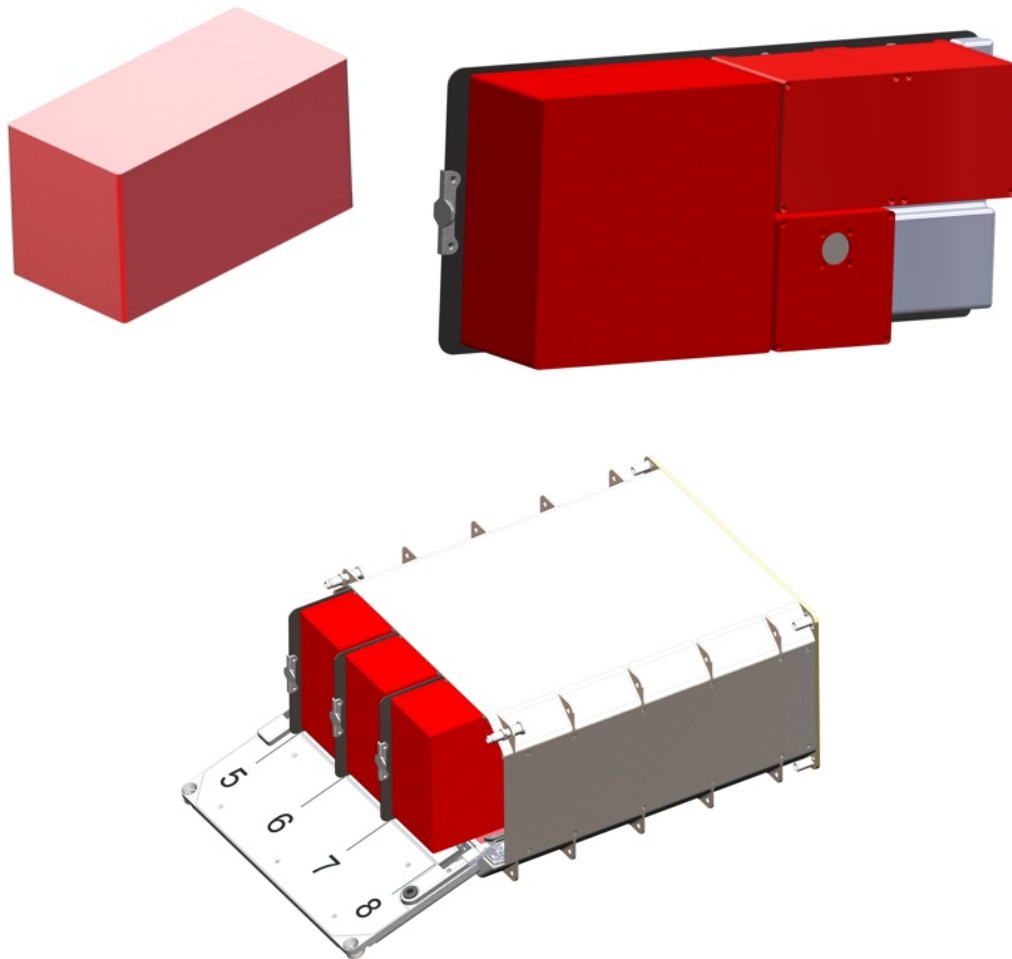


Figure 1: TangoLab Process Flow

2.1 Nomenclature

The terms below describe the nomenclature used throughout the TangoLab architecture and this document.

2.1.1 CubeLab™

A CubeLab (Figure 2) is an individual unit used to contain an experiment and is responsible for environmental control beyond facility ambient conditions as well as analytics for the study

contained. These modules are designed to run autonomously and report data once activated in the TangoLab. CubeLabs are identified by size in units per section 3.2 of this document.



Figure 2: 2U CubeLab Module

2.1.2 Payload Card

A Payload Card (Figure 3) is the mechanical and electrical interface between CubeLabs and the TangoLab. Each Payload Card is made of anodized aluminum and holds up to 7U worth of CubeLabs containing the required Lab Management Cards (LMCs) for each CubeLab. These LMCs report to a top level flight computer. Adherence to the electrical and software requirements and verifications in this document will ensure proper power distribution and data reporting during operations on ISS.

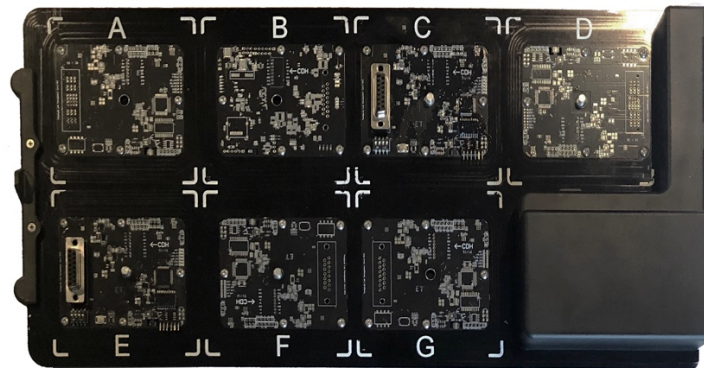


Figure 3: Payload Card

2.1.3 TangoLab Facility

The TangoLab facilities are reconfigurable experiment ecosystems designed for microgravity R&D and pilot manufacturing aboard the ISS. Providing mechanical, electrical and network interfacing the facility can hold up to 21U of CubeLabs, 3 Payload Cards with 7U of CubeLabs each. The TangoLab-1 facility was installed on the ISS on August 1, 2016 and the TangoLab-2 facility was installed on August 17, 2017.

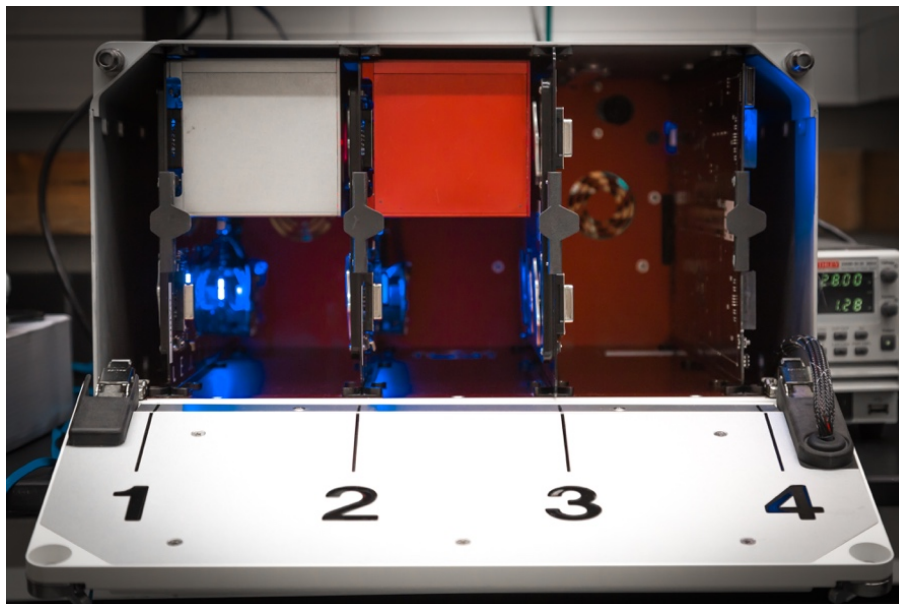


Figure 4: TangoLab-1 Facility

3 Mechanical Interfaces

3.1 Coordinate Convention

To utilize the full volumetric capacity of the TangoLabs, strict adherence to the CubeLab outer envelope is required. All references to coordinate systems within this document follow the orientations of Figure 5.

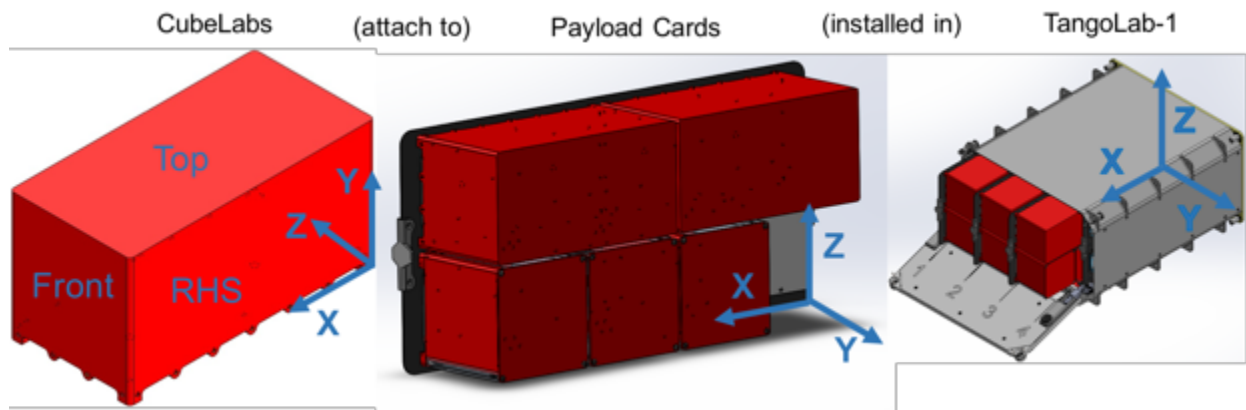


Figure 5: Coordinate Convention of TangoLab Components

3.2 CubeLab Scaling

CubeLabs are identified by unit volumes similar to the CubeSat standard for small satellites. CubeLab sizes are selected based on experimental requirements. All currently available CubeLab sizes are detailed in Appendix A.



Figure 6: Various CubeLab Sizes

3.2.1 CubeLab Volume

CubeLabs shall be no larger than the dimension outlined in Table 1 following the axis key of Figure 5. Detailed mechanical drawings for each volume are shown in Appendix A of this document.

Table 1: Standard CubeLab Volumes

Volume	X	Y	Z
1U	4.000" (101.60)	4.262" (108.25)	4.000" (101.60)
2U	8.150" (207.01)	4.262" (108.25)	4.000" (101.60)
4U	8.150" (207.01)	4.262" (108.25)	8.150" (207.01)
6U	12.300" (312.42)	4.262" (108.25)	8.150" (207.01)
9U	12.300" (312.42)	6.390" (162.31)	8.150" (207.01)

3.2.2 Standoff Height

CubeLabs shall have a standoff height of at least 0.262" (6.65 mm) (Figure 7).

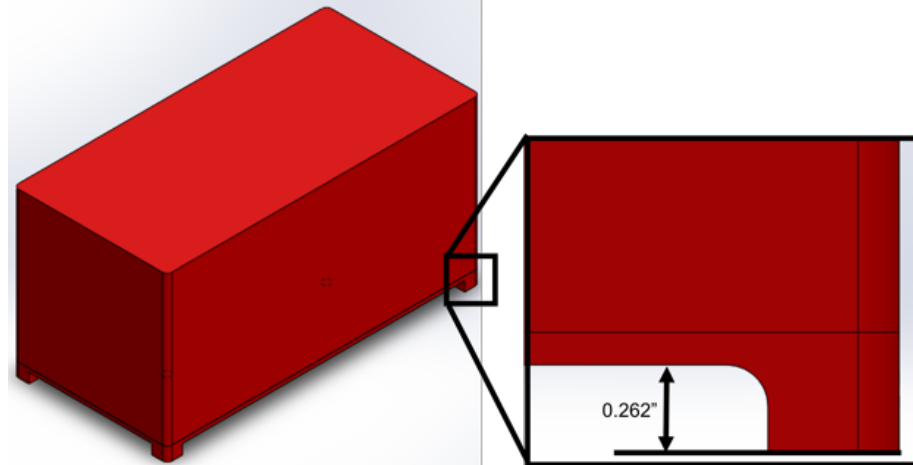


Figure 7: CubeLab Standoffs

3.2.3 CubeLab Spacing

Integrated CubeLabs are separated from one another by 0.150" (3.18mm) in both the Y and Z directions per the CubeLab axis convention and shown in Figure 8.

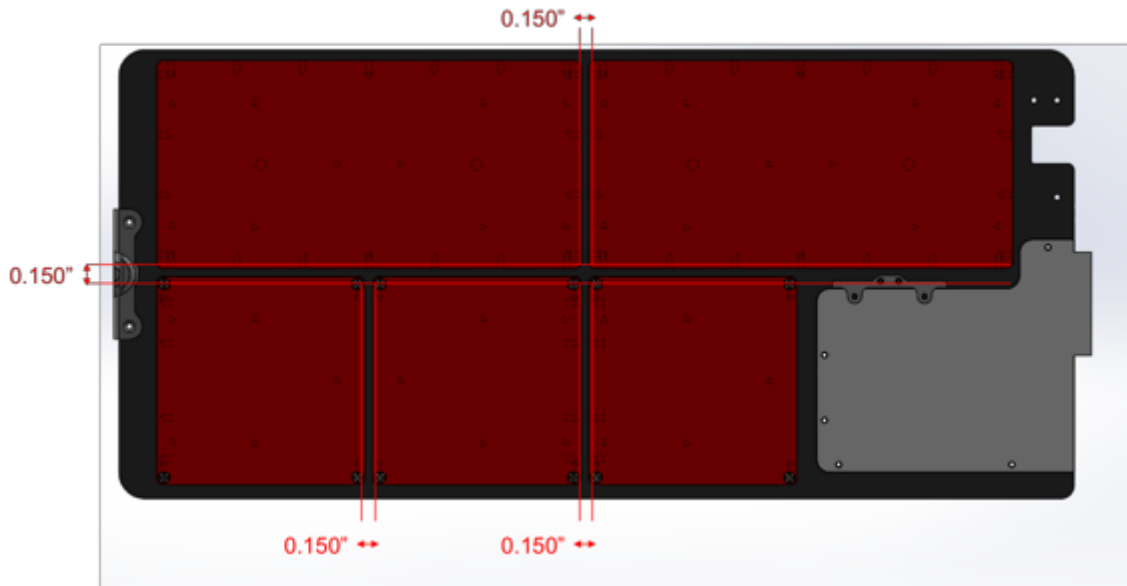


Figure 8: CubeLab Spacing

3.2.4 Connector Location

CubeLabs shall locate the 15 pin D-Sub connectors at the locations relative to their maximum envelope shown in the respective detailed drawing in the Appendix A of this document.

3.3 Mass Properties

3.3.1 Mass

CubeLab modules shall not exceed the mass allotments shown in Table 2. If additional mass is required, contact Space Tango for approval.

Table 2: CubeLab Maximum Mass Allotments

Size	Lbs.	Kg
1U	2.2	1.0
2U	4.4	2.0
4U	8.8	4.0
6U	13.2	6.0
9U	19.8	9.0

3.3.2 Center of Gravity

As of this revision, there are no requirements regarding CubeLab Center of Gravity for use inside the TangoLab facilities. Developers with rotating equipment shall coordinate with Space Tango engineering to ensure that no additional Center of Gravity requirements should be added.

3.4 Attachment Stand

Payload Cards include a fastener as a mechanical attachment with CubeLabs. This ensures a secure connection during activation in the TangoLab and allows for easy CubeLab connection and disconnection.

CubeLabs shall include a 12-24 UCF threaded attachment stand on the bottom face for the mating Fastener (Figure 9). This fastener is inserted through the Payload Card, into the attachment stand of the CubeLab, and tightened to create a secure mechanical connection. The required dimensions and locations for these attachment stands are shown for the respective volumes in the Appendix A of this document.

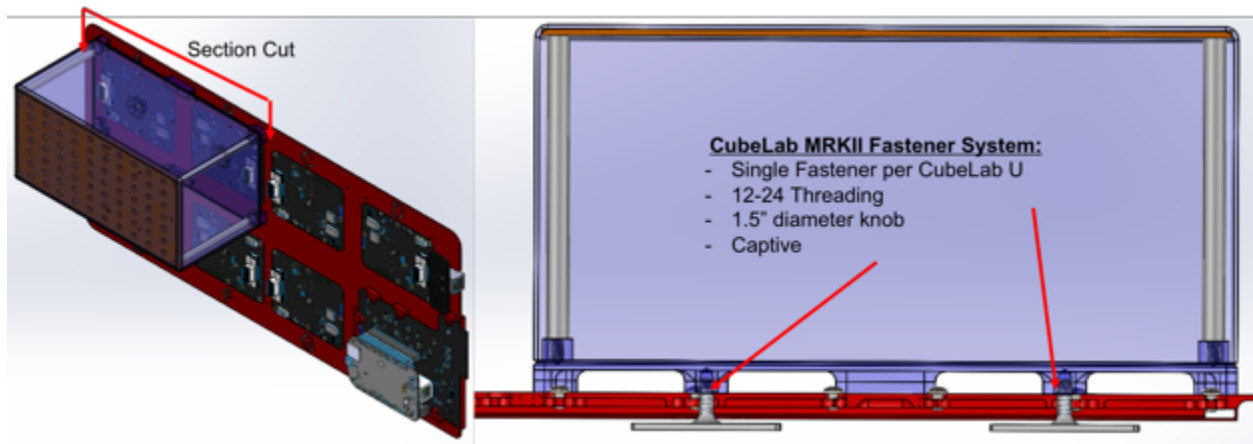


Figure 9: CubeLab Attachment to Payload Card

3.5 Custom CubeLab Structures

It is possible to develop a custom CubeLab structure for an individual payload. Please contact Space Tango to request this capability.

4 Electrical Interfaces

4.1 Voltage & Current Specifications

Payload Cards provide power to the CubeLabs via LMCs. Each LMC position can provide 3.3V, 5V, and 12V power rails to a CubeLab with a shared ground reference. The number of LMCs that are available to a CubeLab depend on the number of CubeLab connectors for a specific sized structure (Appendix A). The quantity of requested LMCs per CubeLab shall be approved by Space Tango prior to use.

Based on payload requirements, CubeLabs can be used with either Standard or High Power LMCs. Only one High Power LMC can be used per payload. Any use of High Power LMCs shall be approved by Space Tango prior to use.

Table 3: LMC Maximum Current Specifications

STANDARD LMC (Default)		HIGH POWER LMC	
Power Rail (V)	Max Current Allowable (A)	Power Rail (V)	Max Current Allowable (mA)
3.3	2	3.3	N/A
5.0	2	5.0	N/A
12.0	1	12.0	6A

4.2 Current Limit Enforcement

Payload Cards enforce current limits via two methods:

1. Software controlled high side switch
 - Software-controlled current limits can be coordinated with the user to provide 'soft limits' for the payload current.
 - If the average current draw is greater than the software-controlled current limit for a period of 160ms, the payload will be disabled.
 - The payload is capable of being re-enabled while in the TangoLab facility if agreed upon by the user and the Space Tango Flight Operations Team.
2. Fast acting chip fuse for short protection
 - Fast acting chip fuse shall trip within 5ms and disable the payload if payload currents exceed the maximum allowable currents outlined in Table 3.
 - If the fast acting chip fuse is triggered, the payload will remain disabled for the duration of the mission.

4.3 CubeLab Connector – Standard LMC

CubeLabs shall use a 15-pin, male D-Sub connector to interface with the Standard LMC. The LMC 15-pin, female D-Sub pinout is shown in Figure 10. The pin out is detailed in Table 4. A secondary USB interface is available – contact Space Tango to request.

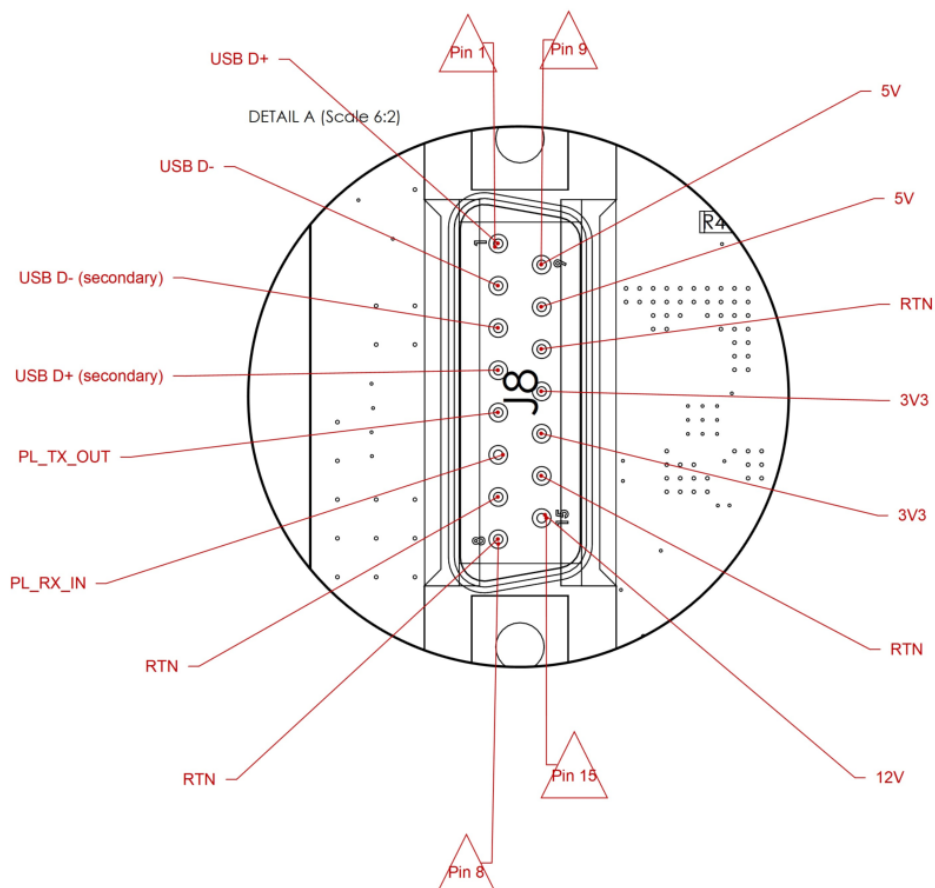


Figure 10: Standard LMC Connector Pin Out

Table 4: Standard LMC Connector Pin Out

Pin	Assignment	Pin	Assignment
1	USB D+ (Primary)	9	5V
2	USB D- (Primary)	10	5V
3	USB D- (Secondary)*	11	RTN
4	USB D+ (Secondary)*	12	3.3V
5	Payload Transmit output	13	3.3V
6	Payload Receive input	14	RTN
7	RTN	15	12V
8	RTN	-	-

4.3.1 Common Return Line

Each of the return lines shall be respectively tied together to minimize ground loops.

4.4 CubeLab Connector – High Power LMC

CubeLabs shall use a 15-pin, male D-Sub connector to interface with the High Power LMC. The 15-pin female LMC D-Sub pinout is shown in Figure 11. The pin out is detailed in Table 5.

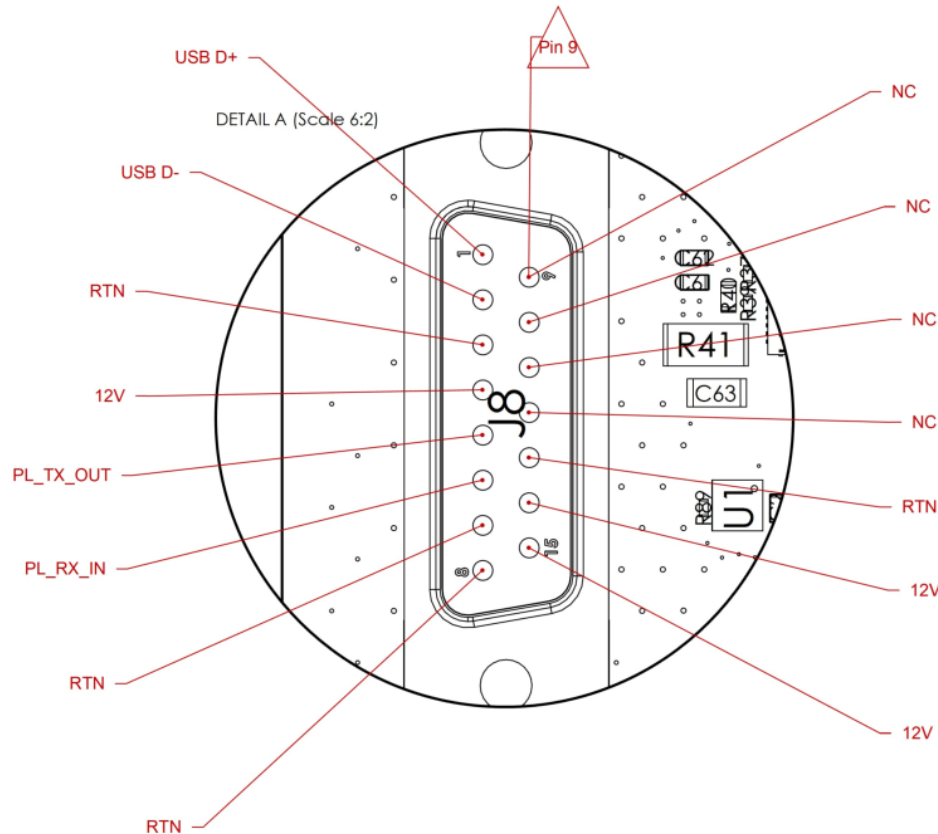


Figure 11: High Power LMC Connector Pin Out

Table 5: High Power LMC Connector Pin Out

Pin	Assignment	Pin	Assignment
1	USB D+	9	NC
2	USB D-	10	NC
3	RTN	11	NC
4	12V	12	NC
5	Payload Transmit output	13	RTN
6	Payload Receive input	14	12V
7	RTN	15	12V
8	RTN	-	-

4.4.1 Common Return Line

Each of the return lines shall be respectively tied together to minimize ground loops.

4.5 Connector Location

The X-Y position of the D-Sub connectors are shown in the respective CubeLab volume in Appendix A of this document.

4.5.1 Connector Depth

The X position of the required D-Sub connector is shown below in Figure 12 measured from the sled of the CubeLab to the bottom of the D-Sub flange.

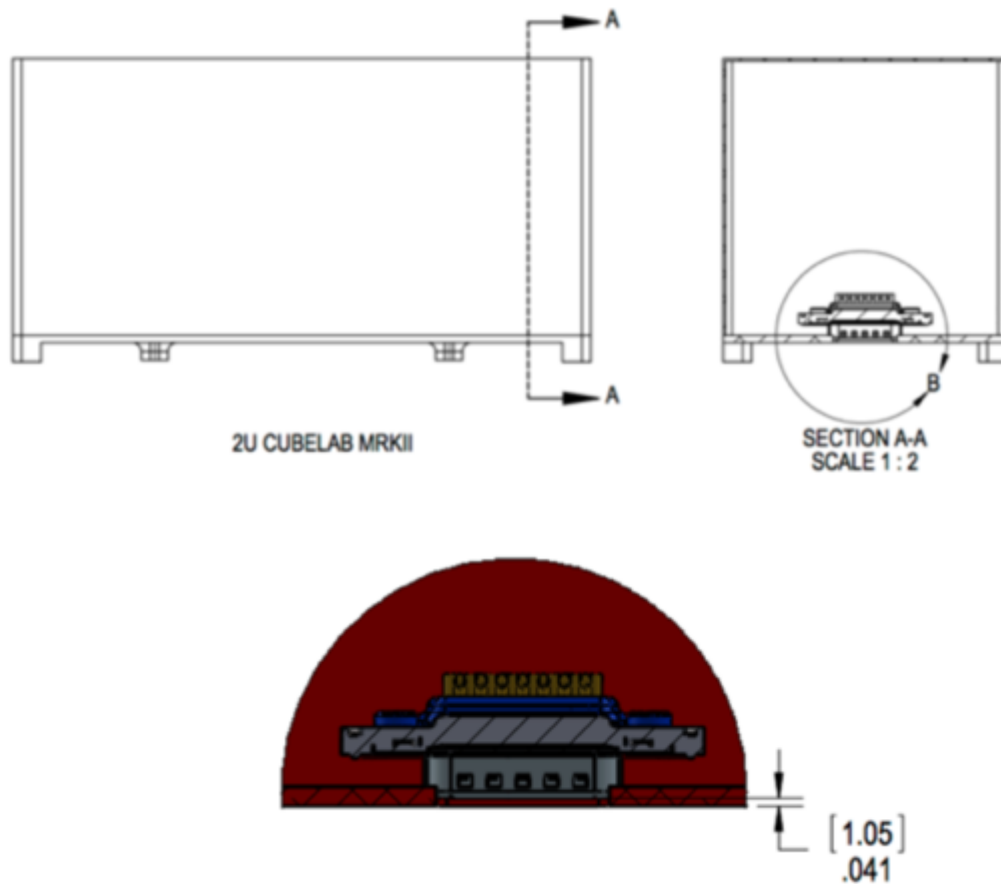


Figure 12: CubeLab Connector Position

4.6 Bonding

A Class H bond (<0.1 Ohm) shall be measured between the CubeLab and Payload Card return lines to ensure proper bonding.

4.7 Isolation

A resistance of $> 1\text{M}\Omega$ shall be measured between the power return line and the external surface of the CubeLab module to ensure proper isolation.

4.8 Shock Hazards

Circuits which boost voltages above 32V DCrms shall be reported to Space Tango Engineering for approval. These circuits will require further coordination of design, testing and documentation.

4.9 Wiring

All power wiring shall be PTFE (Teflon) coated and appropriately sized to 150% of the designed maximum current.

4.10 Capacitor Selection

Payload should avoid using electrolytic capacitors due to the potential hazard of fluid leakage. Tantalum, aluminum and ceramic are acceptable. If electrolytic capacitors are required, contact Space Tango.

5 Communications

Payload Cards consist of a Command and Data Handling Single Board Computer (C&DH SBC) and multiple Lab Management Cards (LMCs) each with a 15 pin D-sub connector. Each LMC position includes a UART interface and single USB connection that connects back to the C&DH. The UART interface is the primary mechanism for telemetry gathering. Between the C&DH and the payload LMC connection there are two cascaded High-Speed (480 Mbit/s) USB hubs. There is currently no direct interface between the UART interface and the USB passthrough connection unless made within the CubeLab itself.

A time server is not provided to payload developers. If a payload requires accurate time keeping, this functionality must be provided internal to the payload. Payloads should use Energizer-CR1220 battery if battery backup is required. If the Energizer-CR1220 battery is not feasible to the design, contact Space Tango to discuss alternate solutions.

5.1 Telemetry interface (UART)

The TangoLab provides a single 0V to 3.3V 8-N-1 Universal Asynchronous Receiver/Transmitter (UART¹) interface for Payload Developers to downlink experiment data. Exceeding 3.3V on the UART TX/RX pins would cause damage to this interface. The default baud rate for this interface is 115200 and not reconfigurable on orbit. A non-default baud rate must be coordinated with Space Tango before payload integration. Payload packets should be formed in accordance with the outline described below in Table 6.

Table 6: TangoLab Data Packet Format

Start Sync Characters	Sequence number	Data Payload	Checksum	End Sync Characters
A0BB	0x01 to 0xFF	"Name ₀ ": Value ₀ , "Name ₁ ": Value ₁ , "Name ₂ ": Value ₂ ,, "Name _n ": Value _n	0x0000	BB0A

5.1.1 Start and End Sync Characters:

The sync characters consist of four ASCII bytes that start and end every packet. The start of every packet should be denoted with the string 'A' '0' 'B' 'B'. (Note: '0' is an ASCII zero and not a capital letter.) The end of every packet should be terminated with the string 'B' 'B' '0' 'A', which is simply the reverse of the starting bytes.

¹ The UART protocol is widely used and thus specifications and standards are outside the scope of this document. Please refer to standard references for the protocol.

5.1.2 Sequence number:

A sequence number is a byte that ranges from 0x01 to 0xFF (1 to 255) and increments by 1 on subsequent sent packets. This number shall roll over to 0x01 when incrementing 0xFF. This helps ensure packet continuity; however, there is currently no packet re-request feature now unless it is built in by the developer.

5.1.3 Data Fields:

The data that Payload Developers generate shall be formed as name/value pairs, separated by commas. Each name shall be unique from all other names and encoded in ASCII. For example, a payload with two temperature sensors, one pressure sensor, and one time-keeper could report data in the following string:

```
"temperature1":98,"temperature2":96,"temperature3":95,"pressure":299,"experiment_time":  
"050259"
```

The *name* portion can be any string that the payload developer desires, as long as it is unique from all other *name* strings. *Name* strings shall be surrounded by the double quote character " (hex 0x22). The *value* portion can be any of the following data types: integer, float or string. If a *value* is a string, it must be surrounded in double quotes. Non-base 10 numbers shall be represented as a string. For example, a base 16 number shall be "00502A" or "002001".

The name/value pair shall be separated by a colon character: (hex 0x3A). Each *name/value* pair must retain the same data type for the duration of the experiment on orbit. Using the above example, "temperature1" could be a floating-point value, and must ALWAYS be a floating-point value. "temperature2" could be a signed integer but must ALWAYS be a signed integer. Care should be taken to avoid using ASCII characters " (hex 0x22) and : (hex 0x3A) as the *name* field to ensure proper reception of data payload.

5.1.4 Checksum:

CubeLabs shall utilize the Fletcher-16 algorithm² to generate a two-byte non-ASCII checksum for ensuring error free data prior to downlink. The buffer used in this algorithm shall include the start sync characters and the data payload as seen in Figure 13. Note that the checksums shall **not** include the end sync bytes. Examples for calculating and verifying the checksum using the C language can be seen in Figure 14 and Figure 15.

```
uint8_t* buffer =  
"A0BBx"temperature1":98,"temperature2":96,"temperature3":95,"pressure":299,"experimen  
t_time":"050259"";
```

Figure 13 - Code snippet indicating buffer for calculating checksum

² References and software libraries for Fletcher algorithms are readily available online.

```
/**
 *      \fn append_checksums
 *      @brief Appends checksums onto the end of a packet
 *
 *      Uses a Fletcher's Algorithm checksum to append two checksum bytes onto end of
 *      message.
 *      NOTE: the calling function MUST ensure that buffer is declared large enough
 *      to support appending two checksum bytes to the end
 */
void append_checksums(uint8_t* buffer, uint8_t buffer_length)
{
    //declare checksum bytes
    uint8_t CK_A = 0;
    uint8_t CK_B = 0;
    //loop counter
    uint8_t j = 0;

    //Calculate checksum of the buffer
    for (j = 0; j < (buffer_length); j++)
    {
        //Fletcher Algorithm
        CK_A += buffer[j];
        CK_B += CK_A;
    }

    //Append checksums to last two bytes of packet
    buffer[buffer_length] = CK_A;
    buffer[buffer_length + 1] = CK_B;
}
```

Figure 14 - Code snippet in C indicating a method to calculate and append checksums to buffer

```

/**
 *      \fn verify_checksums
 *      @brief Verifies checksums at the end of a packet
 *
 *      Computes Fletcher's Algorithm checksums on a packet and compares
 *      to the last two bytes of the packet to make sure the checksums are
 *      correct.
 */
uint8_t verify_checksums(uint8_t* buffer, uint8_t buffer_length)
{
    //declare checksums
    uint8_t checksum_a;
    uint8_t checksum_b;
    //test checksums
    uint8_t CK_A = 0;
    uint8_t CK_B = 0;
    //loop counter
    uint8_t j;
    //flag to return success of checksum calculation
    uint8_t checksum_error = 0;

    //store the packet checksums from the last two positions of the packet
    //These were computed on the sender
    checksum_a = buffer[buffer_length - 0x02];
    checksum_b = buffer[buffer_length - 0x01];
    //loop through the packet and compute checksums (excluding the tailing two checks
um bytes
    for (j = 0; j < (buffer_length - 0x02); j++)
    {
        // Fletcher Algorithm
        CK_A += buffer[j];
        CK_B += CK_A;
    }
    //If the checksums are not equal to the calculated, then there is an error in the
packet.
    if (checksum_a != CK_A || checksum_b != CK_B)
    {
        checksum_error = 1;
    }

    return checksum_error;
}

```

Figure 15 - Code snippet in C indicating how to verify checksum bytes attached to end of buffer

5.1.5 Default Specifications:

Requirements deviating from these specifications shall be discussed with Space Tango prior to initial payload design.

- Packet Size:
 - Recurring data: Shall not exceed 300 Bytes/Package
- Packet Frequency
 - CubeLabs shall transmit packets at a maximum frequency of one packet every 5 seconds.

5.2 Commanding interface

A commanding interface is available to send commands to the payload over the telemetry (UART) interface. The commanding workflow is as follows:

1. The Payload Developer provides a binary file containing command to be sent to Payload
2. Space Tango uploads binary file to C&DH SBC and initiates command script.
3. If the binary file is greater than 500 bytes the file will be broken up and sent in 500 Byte packet segments to payload until the entire file has been sent.
4. The Payload Developer is responsible for detecting start and end of command. For more detailed implementation, discuss with Space Tango.

5.3 File Interface

The primary method of downloading files from payloads utilizes a USB to Ethernet connection between the C&DH SBC and the Payload. PDs must coordinate this interface with Space Tango at the earliest possible opportunity to ensure compatibility. This connection can be made in one of two ways:

5.3.1 USB gadget

Space Tango has successfully used additional SBCs in each payload position. The Payload SBC is configured as a USB slave using the dwc2 and cdc_ether usb drivers. This configuration allows the Payload SBC to be enumerated as an Ethernet device on the C&DH. All normal TCP/IP operations can be performed on this Ethernet device. Space Tango primarily uses SSH, rsync, and SCP to interface with Payload SBCs.

5.3.2 USB to Ethernet Dongle

If the Payload SBC has an Ethernet interface, the Payload Developer can use a USB to Ethernet dongle. The Ethernet port plugs into the payload and the USB (5V, GND, D+, D-) plugs into the D-Sub interface on the LMC. The C&DH SBC supports ASIX based USB to Ethernet dongles. This driver is built into the C&DH SBC kernel and is widely supported by many USB to Ethernet adapters.

5.4 Payload Data Dissemination

TangoLab employs a modern data flow architecture to ensure CubeLab developers have access to their on-orbit data regularly. Data that is generated on-orbit will be transferred from the CubeLab to Space Tango ground servers at least three times per week while operating on orbit. Space Tango will provide credentials to secure customer data locker that will be updated with on-orbit data three times per week. This includes telemetry in CSV files and media in their native format. Payload telemetry must conform to section 5.1 to use this interface.

5.4.1 Payload Card Power Telemetry

Payload Cards provide CubeLab developers with automatically generated power usage telemetry. Voltage, current, and power are monitored and provided to payload developers once every 15 seconds (Table 7).

Table 7: Example Power Telemetry Reporting

Time (UTC)	12V current (A)	5V current (A)	3.3V current (A)
1497542958143540000	0.060576	0.029311	0.041036
1497542973841570000	0.060576	0.029311	0.041036
1497542988957980000	0.060576	0.029311	0.041036
1497543003063620000	0.060576	0.027357	0.041036
1497543018179600000	0.060576	0.027357	0.041036
1497543033285620000	0.060576	0.029311	0.041036

The Time column is represented is in Unix Epoch Time in nanoseconds. This is a standard Unix time keeping format where the number listed in the column represents the number of nanoseconds that have elapsed since "00:00:00 Thursday, 1 January 1970 UTC". Conversion tools and software examples can be found on <https://www.epochconverter.com/> to convert to a desired format.

6 Safety

6.1 Materials

A materials overview of the CubeLab shall be submitted to Space Tango in the format shown in Table 8. This information will be combined with other hardware being transported on the same flight and used in the off gassing and flammability assessments Space Tango submits to NASA safety. A more detailed material submission may be required after review.

Table 8: Materials Submission Example

Material	Total Mass (g)
Metallic –Aluminum	-
Metallic -Other	-
3D Printed	
PLA	-
SLA	-
Other	-
PCBs	-
COTs	-
Other	-

6.2 Toxicology

A toxicology report shall be submitted to Space Tango by the developer outlining the fluids (biological and non) and other materials used which do not fit in the categories of Table 8.

Table 9: Materials Submission Example

CubeLab Module	Identification of Material	Origin of Biological Material	Experiment Subsystem	Maximum Concentration per Sample	ATCC #, Strain, and Designation	Additional Information
CUST_EXM01 (Determined by Space Tango)	Macrophages	Donors	Cuvette	0.05 x 10 ⁶ cells / 150 uL	-	
	Macrophages (Fixed)				-	

Table 10: Materials Submission Example

ID Label (CubeLab Module)	Chemical / Reaction Product	Experiment Subsystem	Part # of Subsystem	Maximum Concentration	Maximum # of Samples	Maximum Amount / Sample	Additional Material Characterization
CUST_EXM01 (Determined by Space Tango)	Promocell, C-28055	Cuvette	Channel 1	98.90%	10	50	-
	Penicillin / Streptomycin Sigma A2212		Channel 1 & Channel 2	1.00%	10	10	-

6.3 Energy Storage Devices

Any energy storage devices such as batteries or capacitors (except those used for power filtering) must be reported to Space Tango for proper coordination with NASA safety.

6.4 Acoustics

Noise generators within a CubeLab greater than ambient noise shall be reported to Space Tango for approval. Additional testing may be required.

6.5 Rotating Equipment

All rotating equipment within a CubeLab shall be reported to Space Tango for approval. Additional testing may be required.

6.6 Magnets

All magnets (electro and permanent) within a CubeLab shall be reported to Space Tango for approval. Additional testing may be required.

6.7 Shatterable Material

All shatterable materials within a CubeLab shall be reported to Space Tango for approval. Additional testing may be required.

7 Environment

7.1 Launch Stresses

The launching loading outlined in Table 11 is sample data reported in the SpaceX Dragon Users Guide. These values are worst case and do not reflect the attenuation of packing within soft stowage. The X direction used in Table 11 is the launch vector with Y & Z the lateral directions.

Table 11: Launch Loading

	Axial Min (X)	Axial Max (X)	Lateral RSS (Y & Z)
Maximum Acceleration (G's)	-6.9	1.8	3.5

7.2 Thermal – Ascent/Descent

During nominal operations, the pressurized section of the SpaceX Dragon capsule is anticipated between 18.3C (65F) to 30C (85F). Any thermal requirements on ascent or descent that are not met by the temperature ranges below shall be presented to Space Tango for approval.

7.3 Thermal - TangoLab

Payloads are installed in the TangoLab facility while in use on the ISS. During nominal operations, the TangoLab is anticipated between 26C (78F) to 36C (97F) based on power usage and heat rejection of the payloads installed. Specific thermal requirements during installation in the TangoLab shall be communicated with Space Tango for evaluation.

APPENDIX A: CubeLab Dimensions

