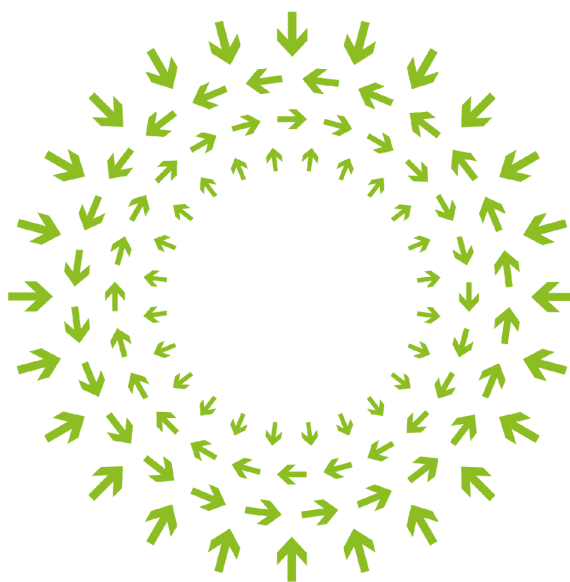




OPEN

Compute Project

Project: Cooling Environments

Project Brazos

0.75.4

Specification

Effective September 11, 2026

Authors: Google

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1. License

THE UPDATED DEFAULT CONTRIBUTOR LICENSE AGREEMENT (CLA) IS [OWFa 0.9](#).
PLEASE VERIFY THE CORRECT CLA/FSA IS USED AND EXECUTED FOR THIS
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2. Compliance with OCP Tenets

2.1 Openness

Google is contributing the rack-mounted, closed-loop liquid-to-air cooling system “Brazos” specification to help enable liquid cooling in air-cooled data centers industry wide. The specification provides technical design details, validation plans and manufacturing quality requirements.

Future versions of the specification are planned to include the supply ecosystem for system components, maintenance, service and deployment procedures that are informed by the 7+ years of liquid cooling at scale experience at Google.

Finally, one of the objectives of opening the specification to the industry is to collect end-to-end feedback to align to a design that can be used widely in first and third party data centers.

2.2 Efficiency

The rack-mounted, closed-loop liquid-to-air cooling system enables deploying high-density, liquid-cooled equipment inside existing air-cooled environments that have sufficient power and standard air handling. “Brazos” helps to avoid retrofitting entire data center facilities with chilled water loops which requires extensive amounts of capital and time.

The “Brazos” rack is targeted to support ~60 kW heat loads within a standard Open Compute Project (OCP) ORv3 form-factor rack. The performance targets are intended to enable more efficient cooling of the next generation AI/ML workloads in air cooled data center environments.

2.3 Impact

The specification will enable any CDU supplier in the industry to develop, manufacture and improve upon the “Brazos” design which is informed by more than 7 years of scale liquid cooling experience at Google. Furthermore, 1st party hyperscalers and 3rd party data center owners alike all over the world would be able purchase a “Brazos” modular unit or rack based on the “Brazos” specification.

2.4 Scale

“Brazos” is assembled from components that are sourced from multiple vendors that are widely known in the industry. Custom components in the “Brazos” rack are intended to

be manufactureable by well-known processes. Beyond supply chain considerations, installation and maintenance procedures are shared to enable fast deployments of reliable equipment. The processes and best practices shared by Google are based on the 7+ years of scale liquid cooling experience.

2.5 Sustainability

Liquid cooling generally requires less electrical power and physical data center space to cool IT hardware compared to air cooling. As such, the “Brazos” performance targets would enable cooling high IT heat loads in the industry with less electricity consumption and/or less data center space. Furthermore, Brazos enables deploying high-density, liquid-cooled equipment inside existing air-cooled environments which helps to avoid retrofitting entire data center facilities with chilled water loops. Finally, since the specification is available to CDU manufacturers globally, data center owners would be able to source CDUs manufactured relatively near to their location.

3. Specification overview

This design specification defines the design and validation requirements for the rack-mounted, closed-loop liquid-to-air cooling system “Project Brazos” specification to help enable liquid cooling of high-power, dense IT pods, including AI/ML ASICs in air-cooled data centers industry wide. The document covers various aspects of the “Project Brazos” system”, including physical dimensions, mechanical data, performance specifications (thermal/hydraulic), functional specifications, electrical specifications, safety and compliance, CAD, manufacturing, packaging, shipping and validation requirements.

3.1 “Project Brazos” system overview

“Project Brazos”, also referred to as “Brazos” or “Brazos rack” in this document, is a rack-mounted air-assisted liquid cooling (AALC) system which includes three modular cooling units and integrated rack manifolds as shown in the schematic diagram depicted in Figure 3.0. Each modular AALC “Brazos unit” (also known throughout the document as “Brazos chassis”, “air CDUs” and “aCDU”) is 11 Open Units (OU) tall and interfaces with standard Open Compute Project (OCP) ORV3 form-factor racks.

The “Project Brazos rack” can be deployed adjacent to the IT machine rack to which it pumps single phase liquid to cool the IT equipment in a closed liquid loop. The heat from the IT equipment is rejected from the liquid to the data center air through an air-to-liquid heat exchanger, or radiator, in the “aCDU”. The cold air is drawn through the aCDU by a bank of fans mounted on the rear of the aCDU and the hot air is exhausted into the data center hot aisle containment. The mechanical design enables field serviceability of the individual “Brazos chassis” as well as field replaceable units (FRUs) within the chassis. The chassis sits on low-friction slides so it can easily be extended for access to FRUs. Critical to function components such as front-serviceable strainers, sealless pump assemblies (with integrated Variable Frequency Drive) and fans are designed to be hot-swappable to minimize mean time to repair (MTTR). Electrical specifications include support for 40-60 Vdc nominal voltage from the Open Rack V3 (ORV3) standard busbar.

Key design, interface and performance parameters include:

- **Rack thermal capacity** (nominal) of 60 kW across three modular units
- **Coolant compatibility** includes deionized (DI) water and 25% propylene glycol mixture (PG25)
- **Power delivery** at 40–60 V DC input designed from direct connection to standard rack busbars
- **Certified** to UL/CSA/IEC 62368-1 standards
- **Safety features** include built-in leak detection alongside pressure relief valves
- **Controls and local monitoring** with built-in human-machine interface (HMI) and remote management via Modbus over TCP.

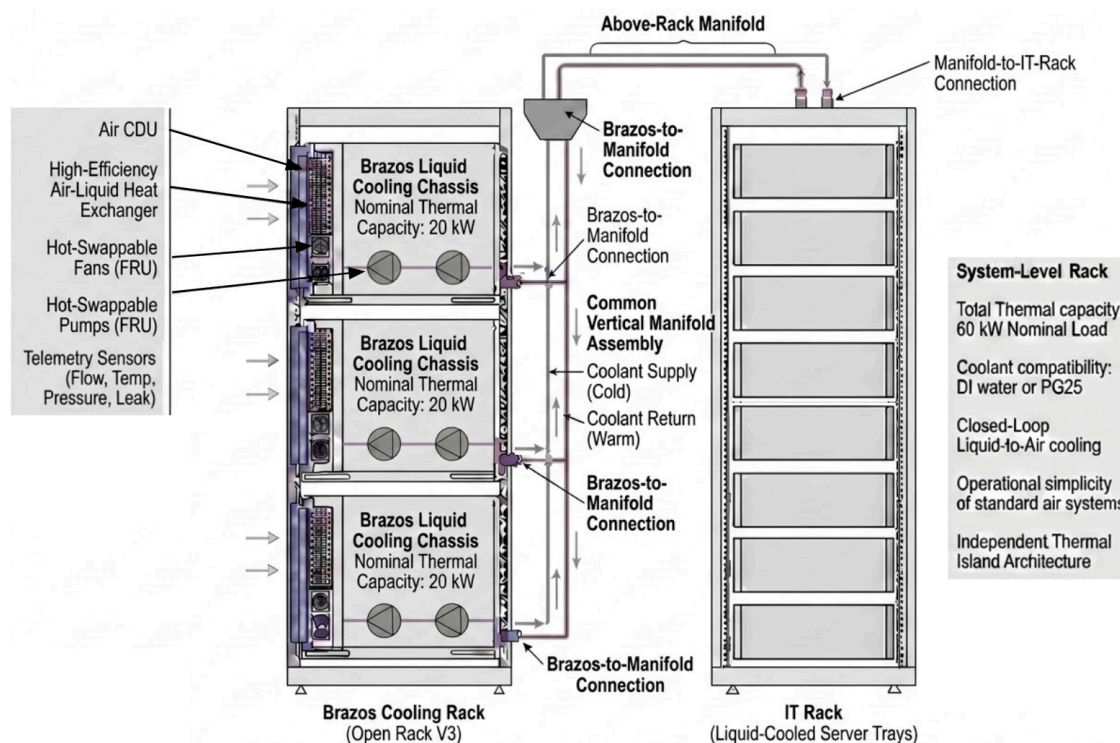


Figure 3.0: Brazos OCP ORV3 Sidecar configuration showing three units providing cooling to an adjacent IT rack.

3.2 Brazos rack technical specifications and interfaces

Table 3.0: Brazos rack technical specifications and interfaces

Design target	Specification
IT flow (GPM), DI water	19
Liquid dP (psi), DI water	25
Rack airflow (CFM)	7700
Max fan speed	
Hot aisle back pressure = 0 in.-H ₂ O	
Maximum liquid pressure (psig)	130
Rack thermal load (kW)	60
Approach temperature (°C)	8
Module weight, wet with DI water (lbs)	261
Module weight, dry (lbs)	248

Rack weight, wet (lbs)	2200
Module max power consumption (kW)	4
Module voltage (VDC)	40-60
Liquids	DI water, PG25
Module dimensions (inches) W x H x D	22.3 x 20.7 x 24
Internet protocol	IPv4, IPv6
Remote control & monitoring	Modbus over TCP
Certifications	UL/CSA/IEC 62368-1

3.3 Brazos rack subsystems and key components

Some of the key components found in a “Brazos chassis” (or “aCDU”, “air CDU”) are shown in Figure 3.1. The complete list of key components is listed below:

- Air-liquid heat exchanger (radiator)
- Fans
- Pumps with check valve (to prevent backflow into non-operational pumps)
- Expansion tank
- Couplings for liquid interconnection between rack manifold and aCDU
- Telemetry hardware
 - Liquid flow
 - Liquid supply & return temperature
 - Inlet air temperature
 - Outlet air temperature
 - Liquid supply pressure
 - Liquid return pressure
 - Power in
 - Power out
 - Voltage in
 - Voltage out
 - Current in
 - Current out
- Power & control board
- Leak detection
- Front-panel HMI

- Check valves to prevent backflow to pump
- Filters/strainers: 325 mesh (44 micron)
- Detachable airflow diffuser/diverter/baffle on rear face/panel of airCDU chassis (prevents relatively large volumes of exhaust airflow from flowing in one direction and potentially impacting nearby IT equipment). The detachable diffuser should ship unattached to the main Brazos chassis.

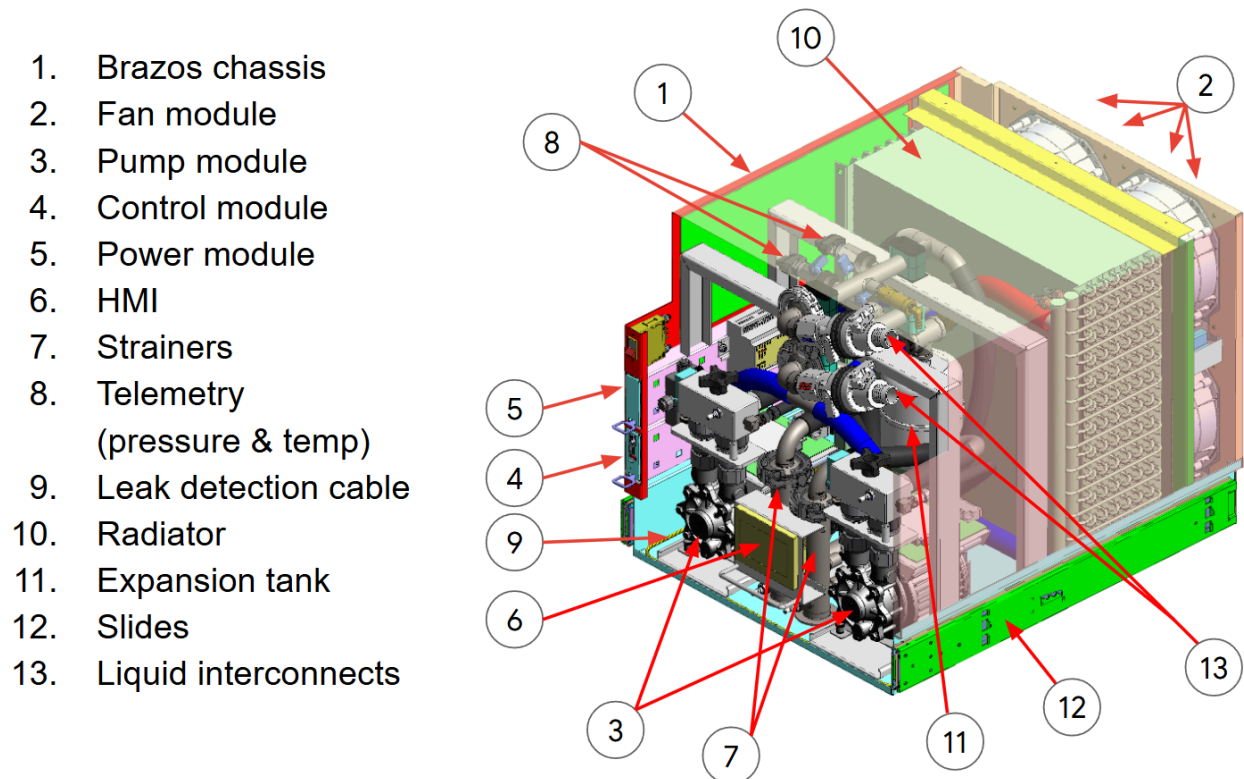


Figure 3.1: “Brazos chassis” key components.

The key components found in a “Project Brazos” rack (or “Brazos rack”) are shown in Figure 3.2 and listed below:

- Rack manifolds
 - Air vent
 - Liquid quick disconnects for connection to IT payloads
- Machine rack leak detection on floor in front of rack (not shown in Figure 3.2)

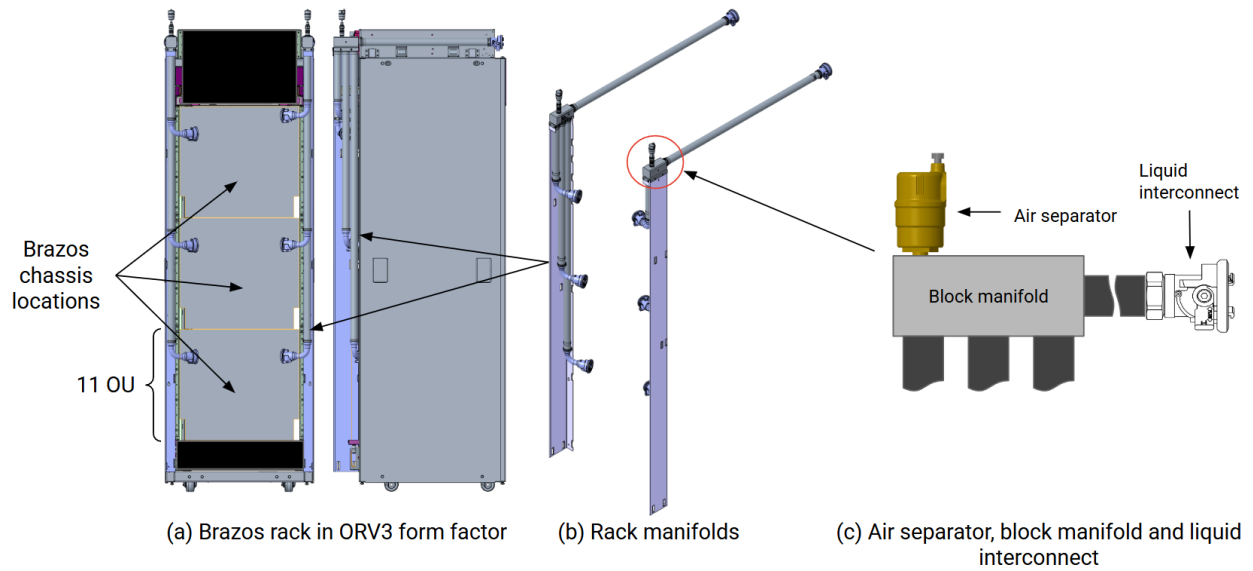


Figure 3.2: “Brazos rack” key components.

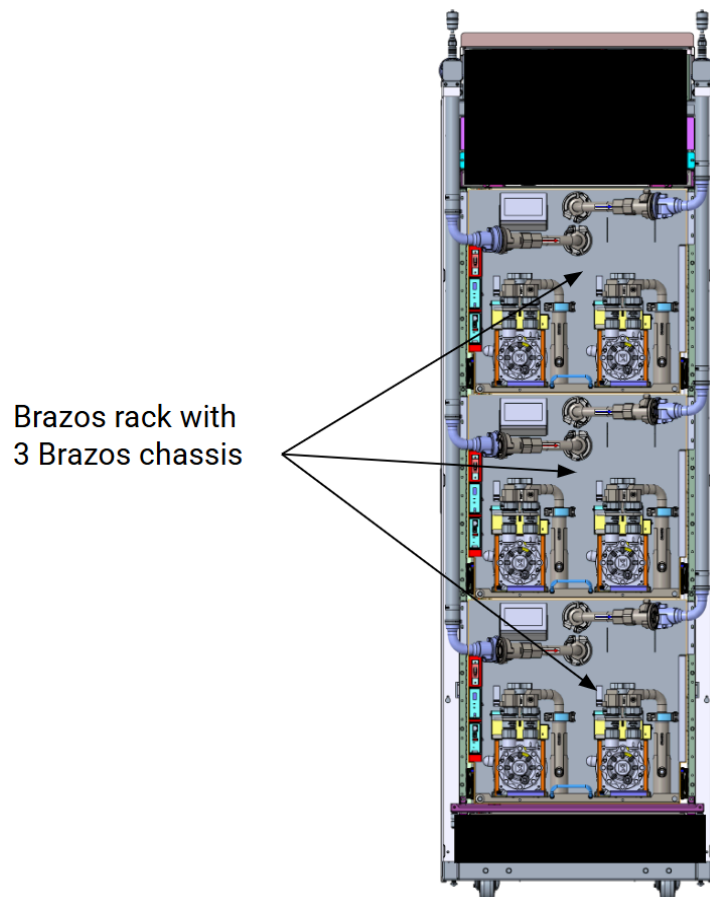


Figure 3.3: “Brazos rack” with 3 “Brazos chassis” installed and rack manifolds.

3.4 Liquid flow and sensor block diagram

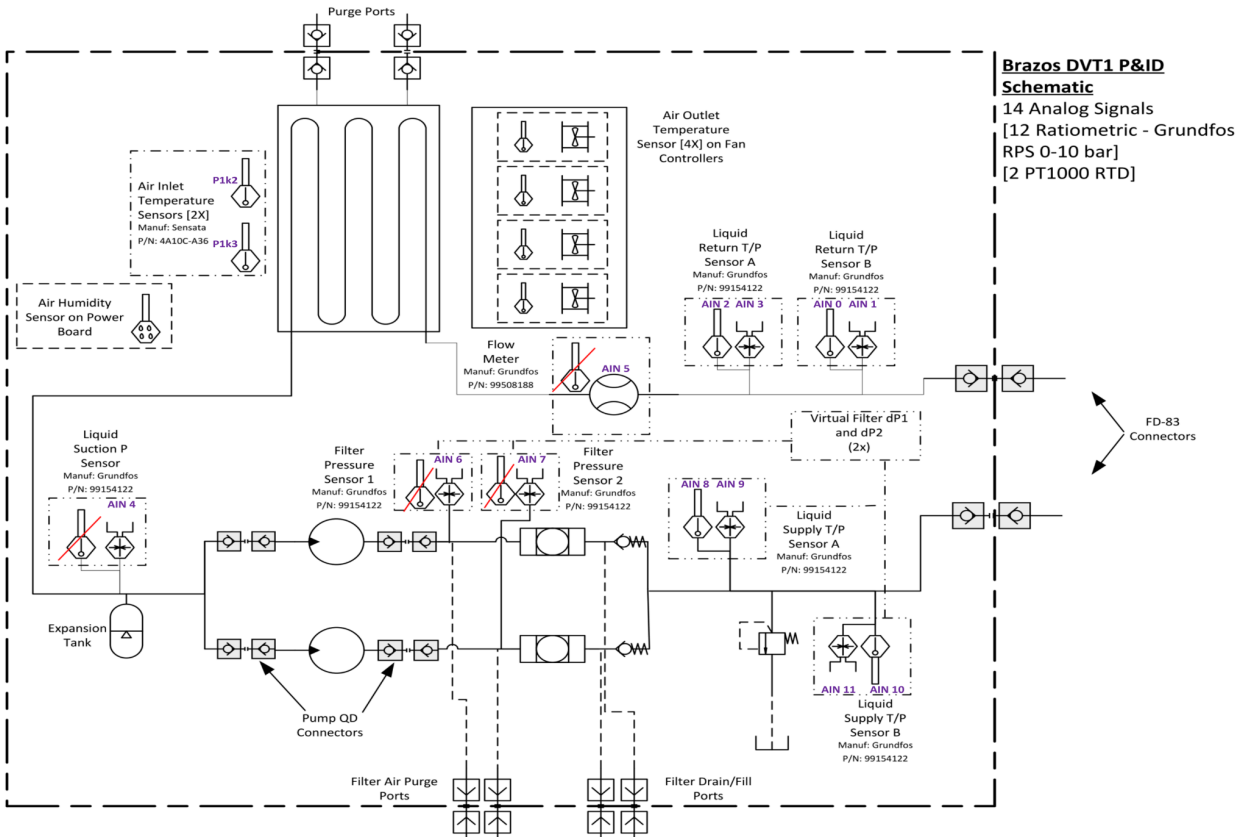


Figure 3.4: Schematic diagram of the Brazos hydraulic circuit with pressure, temperature, flow and humidity sensors. The example sensors in the diagram can be procured from vendors such as Grundfos and Sensata as shown. Each Brazos chassis consists of liquid interconnect couplings such as the FD83 connector shown in the diagram as an example.

4 Thermal-hydraulic performance requirements

4.1 Brazos rack thermal-hydraulic performance

Table 4.1 Brazos thermal performance data vs heat load at nominal liquid flow of 12.8 GPM and nominal external hydraulic load of 24 psi.

Thermal load	30 kW			40 kW			50 kW			60 kW		
Fan speed (%)	60	80	100	60	80	100	60	80	100	60	80	100
Air temperature rise (°C)	15.1	11.3	9.7	20.3	14.6	12.3	24.7	18.6	15.6	27.0	21.6	17.0
Airflow (ACFM)	4143	5944	7715	4098	6021	7812	4049	5848	7593	4100	5924	7808
Liquid flow (GPM/kW)	0.427	0.426	0.426	0.320	0.320	0.320	0.258	0.257	0.257	0.325	0.322	0.321
External dP (psi)	24.1	24.2	24.2	24.2	24.2	24.2	24.2	24.1	24.1	25	25	25
Liquid temperature rise (°C)	9.0	9.0	9.0	12.0	11.9	12.0	14.7	14.8	14.9	11.7	11.8	11.9
Approach temperature (°C)	7.3	4.2	3.0	9.9	5.4	3.8	12.1	7.0	4.9	17.8	11.6	7.5

4.2 Brazos chassis airflow

Table 4.2 Brazos chassis airflow and fan power vs fan speed

Fan speed (%)	Fan speed (RPM)	Brazos unit Fan power (W)	Brazos unit Airflow (SCFM)
28	1987	81	456
54	3750	306	1222
65	4545	566	1555
76	5340	884	1877
88	6150	1327	2213
100	7000	1982	2622

4.3 Brazos rack hydraulic performance

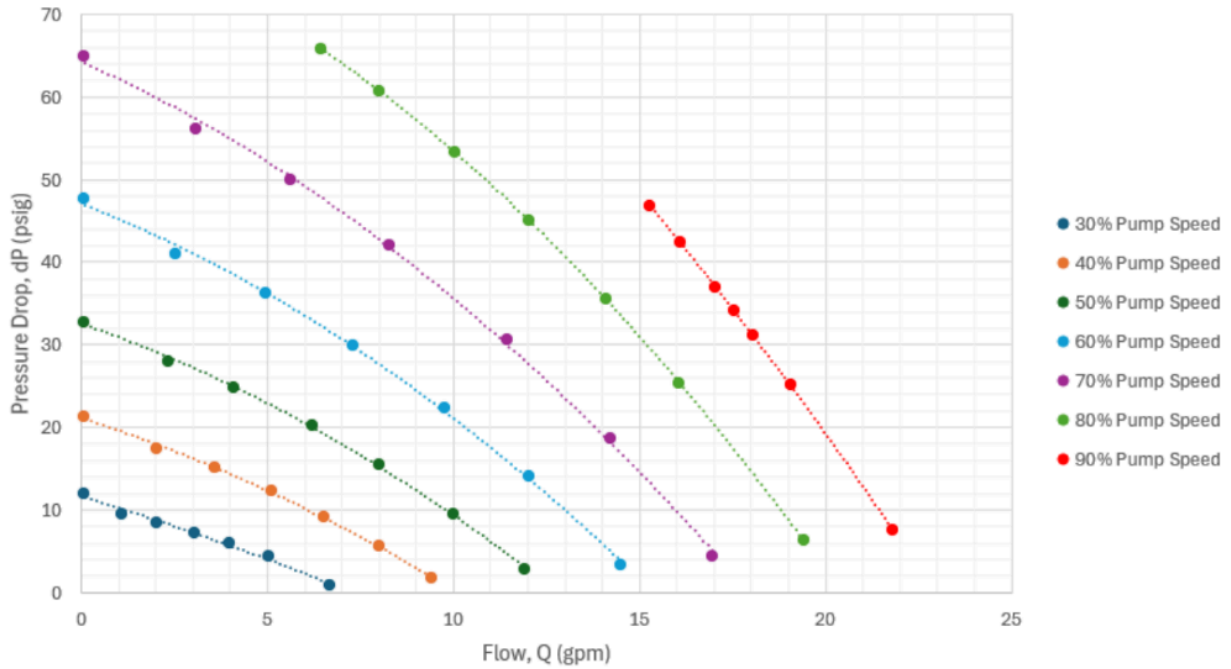


Figure 4.1: Brazos rack hydraulic performance, i.e. available pressure head for an external hydraulic load. Rack contains 3 Brazos chassis each with 2 pumps operating in parallel.

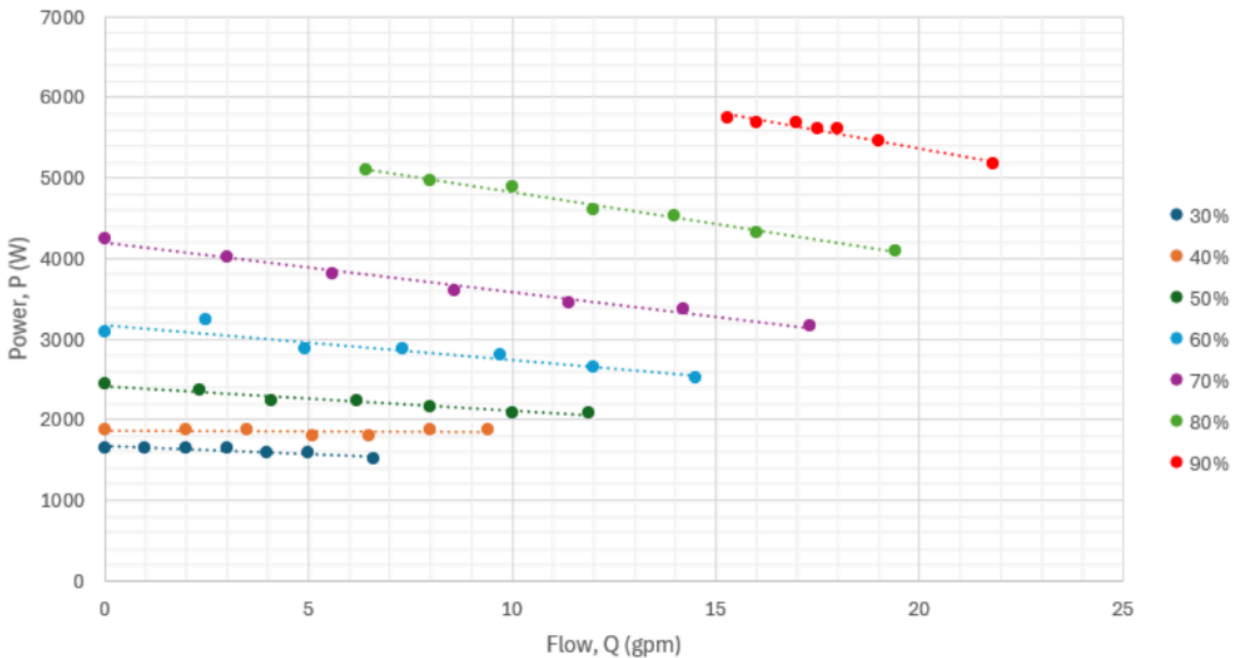


Figure 4.2: Brazos rack pump power consumption. Rack contains 3 Brazos chassis each with 2 pumps operating in parallel.

4.4 Additional requirements

- Brazos chassis and rack thermal performance shall meet or exceed the performance characteristics as shown in Sections 4.1, 4.2 and 4.3.
- Liquid speeds shall not exceed piping erosion limits.
- The supplier shall report heat exchanger effectiveness & NTU vs flow vs thermal load.
- The vendor shall complete liquid side CFD modeling of the design using a customer approved CFD software package (e.g. Macroflow) and share the model with the customer.
- The vendor shall indicate the physical properties (e.g. density, specific heat, viscosity, thermal conductivity) of the fluids (air & liquid) used in the modeling
- The vendor shall complete air side CFD modeling of the design using a customer approved CFD software package (an example of CFD software is FloTHERM) and share the model with the customer.

5 Expansion tank

- Max operating pressure: 150 psi
- Operating temperature: -10 °C to 99 °C
- Nominal volume: 1 L
- Material: stainless steel

6 Environmental

- Nominal ambient temperature: 29 °C, 0-1700 ft
- Elevation and ambien (for thermal-hydraulic performance modeling only):
 - 0-1700 feet @ ambient temperatures 15-40 °C
 - 7600 feet @ ambient temperatures 15-32 °C
- Relative humidity: 8-80%

7 Mechanical

7.1 Weight

The mass of the Brazos chassis must be a manageable weight to enable existing lift assist tools to be used for adding or replacing a Brazos chassis in a rack. The available lift assist tool consists of a platform with a weight limit of 300 lbs in the extended position.

Dry Weight of the Brazos chassis must be less than 250 lbs (113.4 kg). This is with all FRUs installed and inner slides attached, as it would be configured while lifting to mount in the rack, but with all liquid drained and purged with pressurized air.

Full Weight of the Brazos Chassis (with liquid added) must be less than 264 lbs (120 kg). This would be the same configuration as the above Dry Weight, but with fluid in the system and a full reservoir.

7.2 Material Finishes

Materials used in the construction of the Brazos chassis assembly shall have surface finishes with an appropriate level of corrosion resistance. Carbon-steel parts are to be zinc plated. Stainless steel parts are to be passivated. Aluminum parts may be anodized or have a chemical film or chromate conversion coating. A recommended spec for finishing aluminum parts is “CHEMICAL CONVERSION COATING PER MIL-DTL-5541 TYPE II, CLASS 3, CLEAR, OR COMMERCIAL EQUIVALENT.” For the specific materials identified above, any other types of finishing/plating is to be proposed by the supplier to the customer, and approved by the customer. Other coatings (to be proposed & approved) could be for corrosion resistance and/or for reduced friction or to achieve a specific color such as to highlight a touch point. Other materials not specifically identified above are to have finishes common in the industry for corrosion resistance, and must be compatible with the coolant fluid used in the Brazos system.

7.3 Design for Rack Interfaces

Installation of the Brazos product will need to be compatible with multiple rack types. The multiple rack types are summarized as follows.

1. Open Rack V3 Specification (ORV3)
2. Proprietary Rack

Considering the requirement to fit in multiple rack types and another requirement earlier in this document regarding force limits to install/remove the product, it is expected that low-friction slides will need to be pre-installed in the rack to support installation of Brazos. With the use of slides to mount the product, it should be possible to support one common main Brazos chassis with adapter brackets to fit into each rack type.

All of the targeted racks for deployment use the “OU” unit of measurement for height within the rack. Applicable differences in other rack interface features will be included in the following subsections for each rack type. Busbar interfaces for the various rack types are ORV2 compatible and Left justified (observers left when looking at the rack from the front).

7.3.1 ORV3 rack (aka Z2 rack)

The definitions of the interfaces for the ORV3 rack are specified within the *Open Rack V3 Base Specification* Revision 1.0 (OCP shared [PDF](#)), specifically in section 6.2 “Rack Geometry Option 2.” The following [Figure 7.3.1-1](#) is extracted from this referenced specification. Some dimensions shown are relative to support flanges in the rack which will not be used with the

Brazos chassis installation. These dimensions are circled in blue with comments and applicable dimensions are provided in a subsequent figure ([Figure 7.3.1-3](#)).

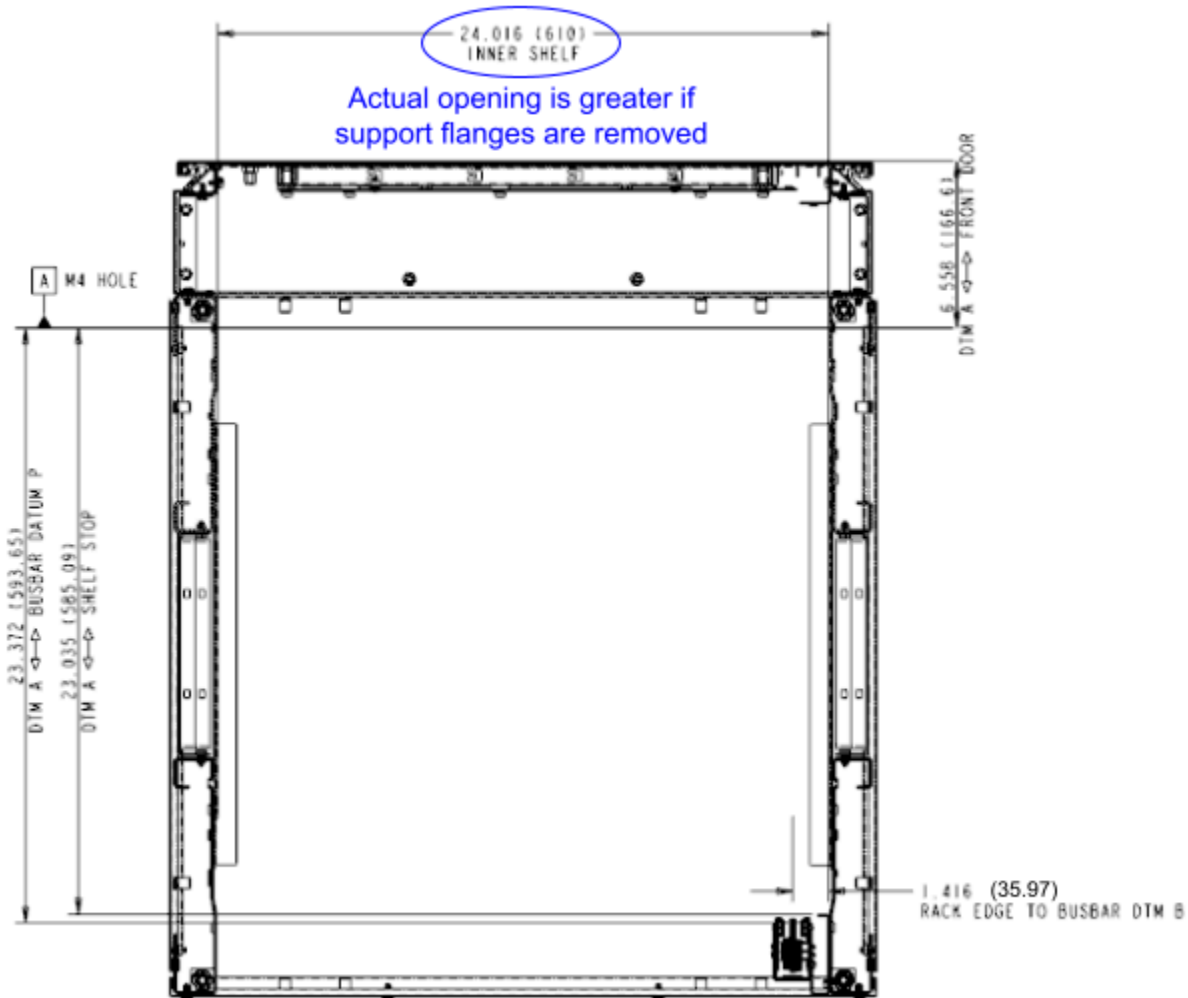


Figure 7.3.1-1: *Commented figure from OCP rack spec*

Going forward, this ORV3 rack will be referred to as the Z2 rack. To assist with any ambiguity or missing details in the aforementioned rack specifications, a 3D model of a 1-OU section will be shared. The 3D CAD filename is "0-brazos_z2_single-ou_section_2024-02-13.stp" (refer to CAD available from OCP). This single-OU section can be patterned vertically at 48mm pitch to represent the height of the rack that the Brazos chassis will occupy. An isometric view of this 3D CAD model as well as a plan-view sketch re-dimensioning key features are in the following [Figure 7.3.1-2](#) and [Figure 7.3.1-3](#). Refer to the 3D CAD model for details not highlighted in these figures.

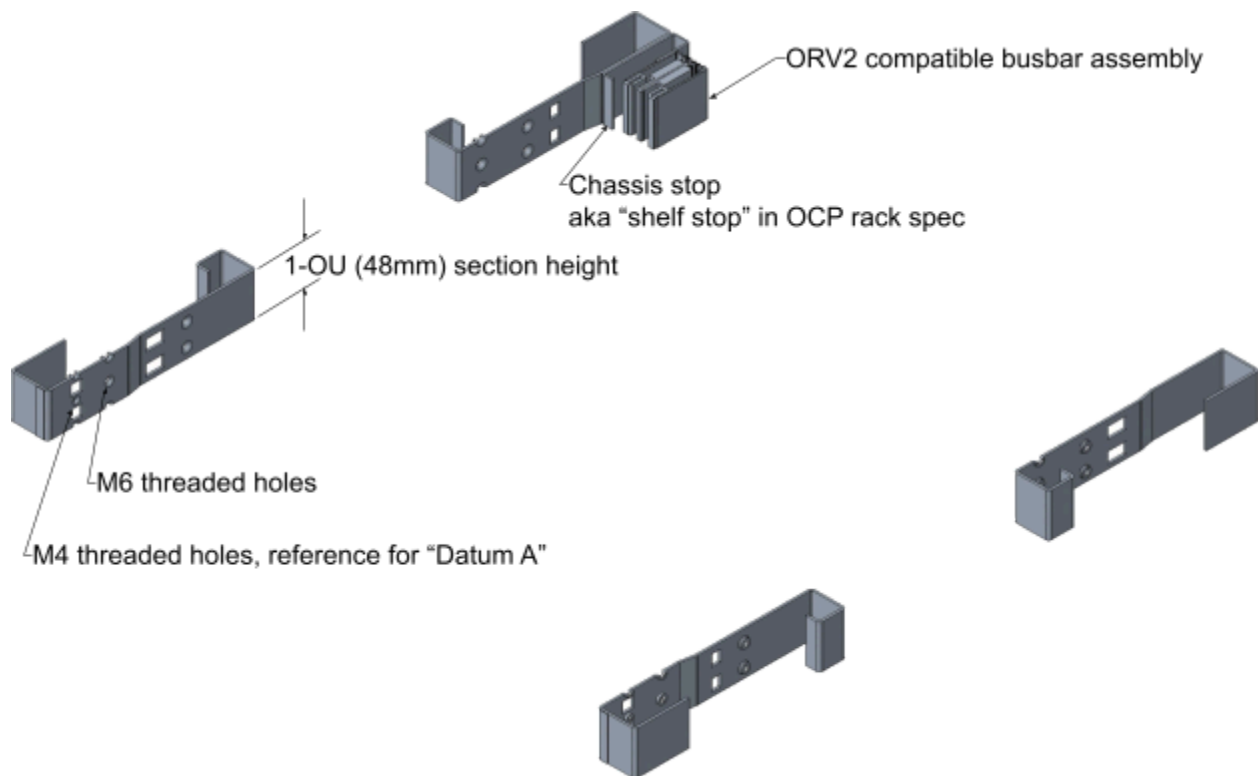


Figure 7.3.1-2: Z2 single-OU section - isometric view

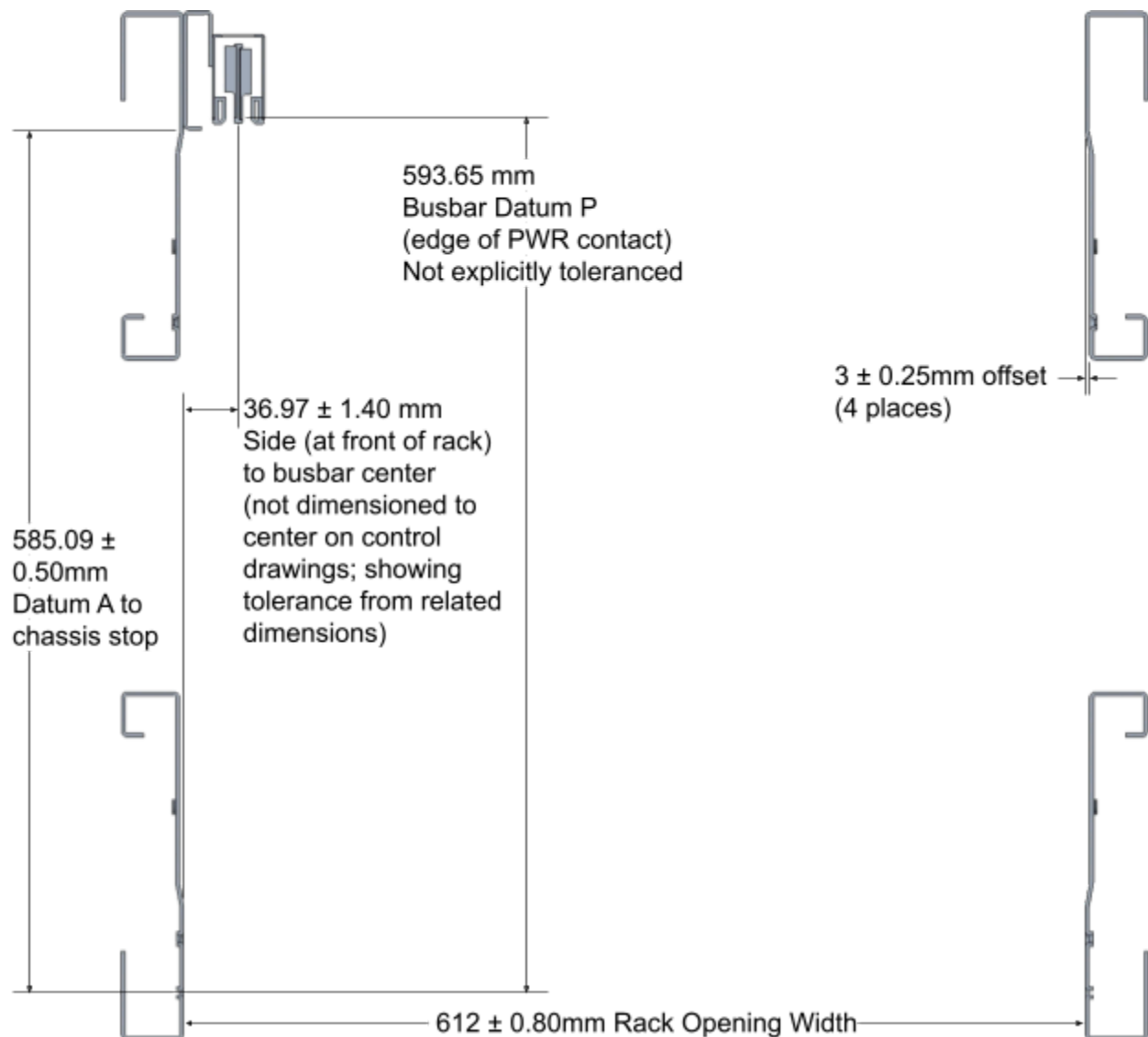


Figure 7.3.1-3: Z2 single-OU section - plan view

7.3.2 Proprietary rack (aka SH rack)

The proprietary rack will be referred to as the SH Rack going forward. The available rack interfaces of the SH rack are very similar to the Z2 rack. The main differences are that the SH rack opening is narrower, and the SH rack also does not include the 3mm offsets in the internal walls of the rack.

A 3D model of a 1-OU section will be shared to aid in designing for this interface. The 3D CAD filename is "0-brazos_sh_single-ou_section_2024-02-13.stp" (refer to CAD available from OCP). This single-OU section can be patterned vertically at 48mm pitch to represent the height of the rack that the Brazos chassis will occupy. An isometric view of this 3D CAD model as well as a

plan-view sketch re-dimensioning key features are in the following [Figure 7.3.2-1](#) and [Figure 7.3.2-2](#). Refer to the 3D CAD for details not highlighted in these figures.

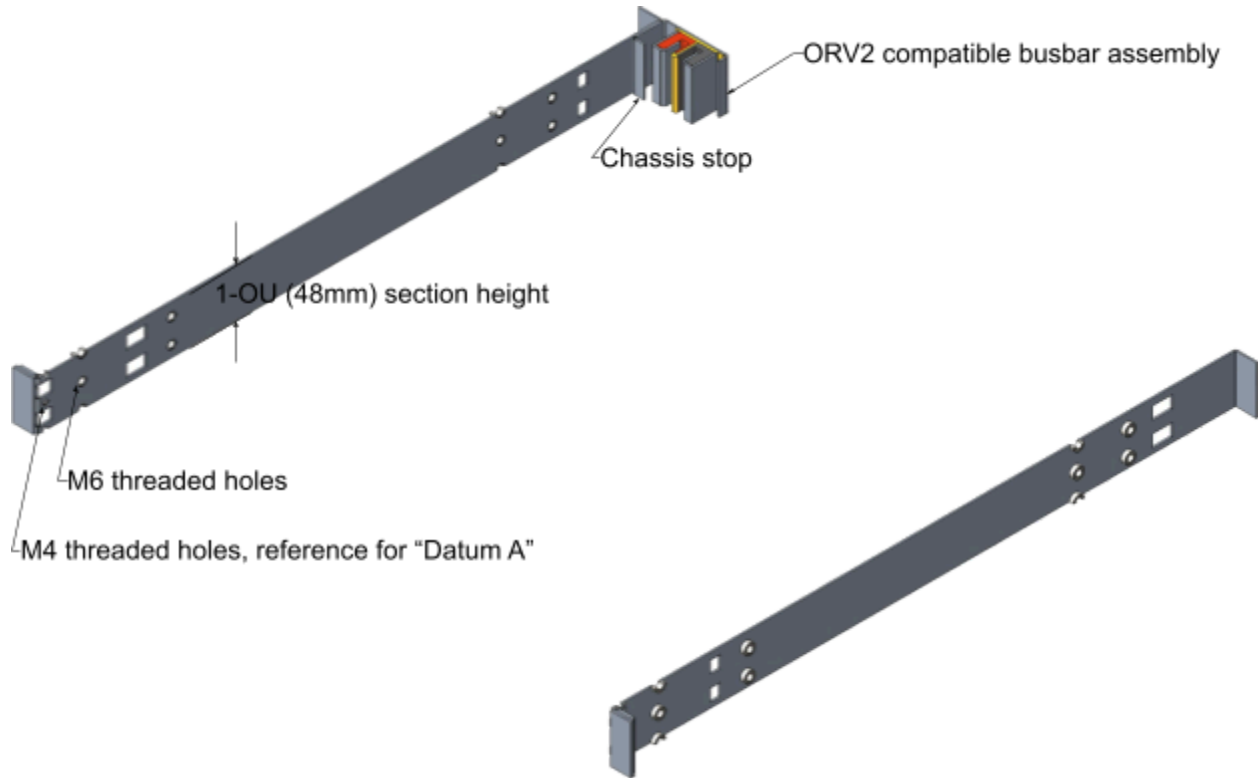


Figure 7.3.2-1: *SH single-OU section - isometric view*

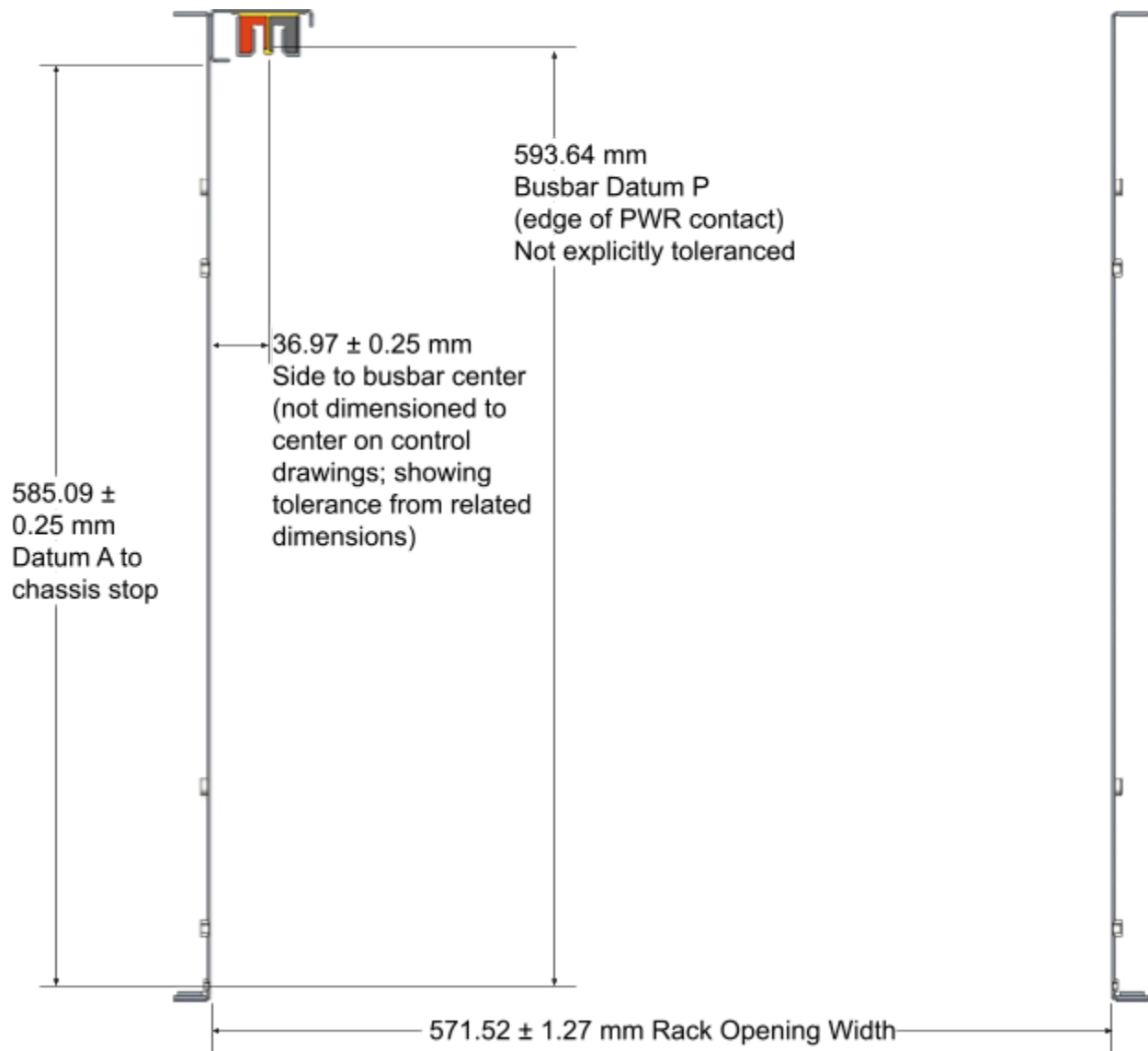


Figure 7.3.2-2: SH single-OU section - plan view

7.4 48V Busbar Mating Power Connector

The power connector within the Brazos chassis which interfaces with the rack vertical busbar is to be an ORV2 compatible connector with enhanced features as identified with the dimensions in the following [Figure 7.4-1](#).

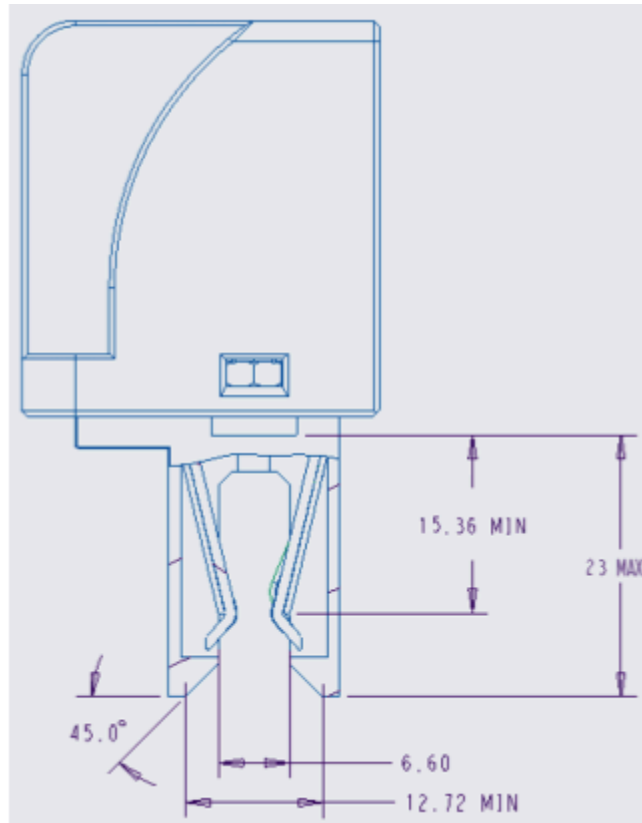


Figure 7.4-1: ORV2 mating busbar connector with enhanced feature dimensions

7.5 Keep-in Volume

The height of the Brazos chassis is limited to 11-OU. Reserving 3mm for a gap between units in the rack, the total nominal height of the chassis is 525 mm. The Brazos chassis front principal face may extend forward of Datum “A” (M4 mounting holes) of the Z2 Rack and the SH Rack by no more than 10.1mm. The depth of the chassis, from front principal face to back principal face is limited to 609.6mm (24 inches), however there is a notch in the back-left corner of the chassis volume for clearance to the rack busbar (notch dimensions of 14.4mm x 65.5mm shown in [Figure 7.5-1](#)). Protrusion allowances are provided in the same figure for the front and back faces to allow for handles, latches, fasteners, etc., as well as the front liquid connections to extend beyond the main volume by a limited distance - front protrusion allowance is 101.6mm and back protrusion allowance is 12.7mm. The width of the chassis is limited by the opening width of the SH rack (which is smaller than the Z2 rack). Allowing gaps on both sides for free motion forward/backward during installation, the nominal width of the chassis is limited to 565.5 mm, however again there are keep out notches along the bottom edges to reserve space for slides & mounting interfaces to the rack (notch dimensions of 25mm x 100mm shown in [Figure 7.5-1](#)). In addition to the figure below, a 3D model will be provided for the keep-in volume. The 3D CAD filename for the keep-in volume is “0-brazos_chassis_keep-in-volume_2024-02-14.stp” (refer to CAD available from OCP); also 3D CAD filename

“0design_brazos_rack_interface_2024-02-14.stp” (refer to CAD available from OCP) is provided for the chassis volume aligned with the 1-OU rack sections described above.

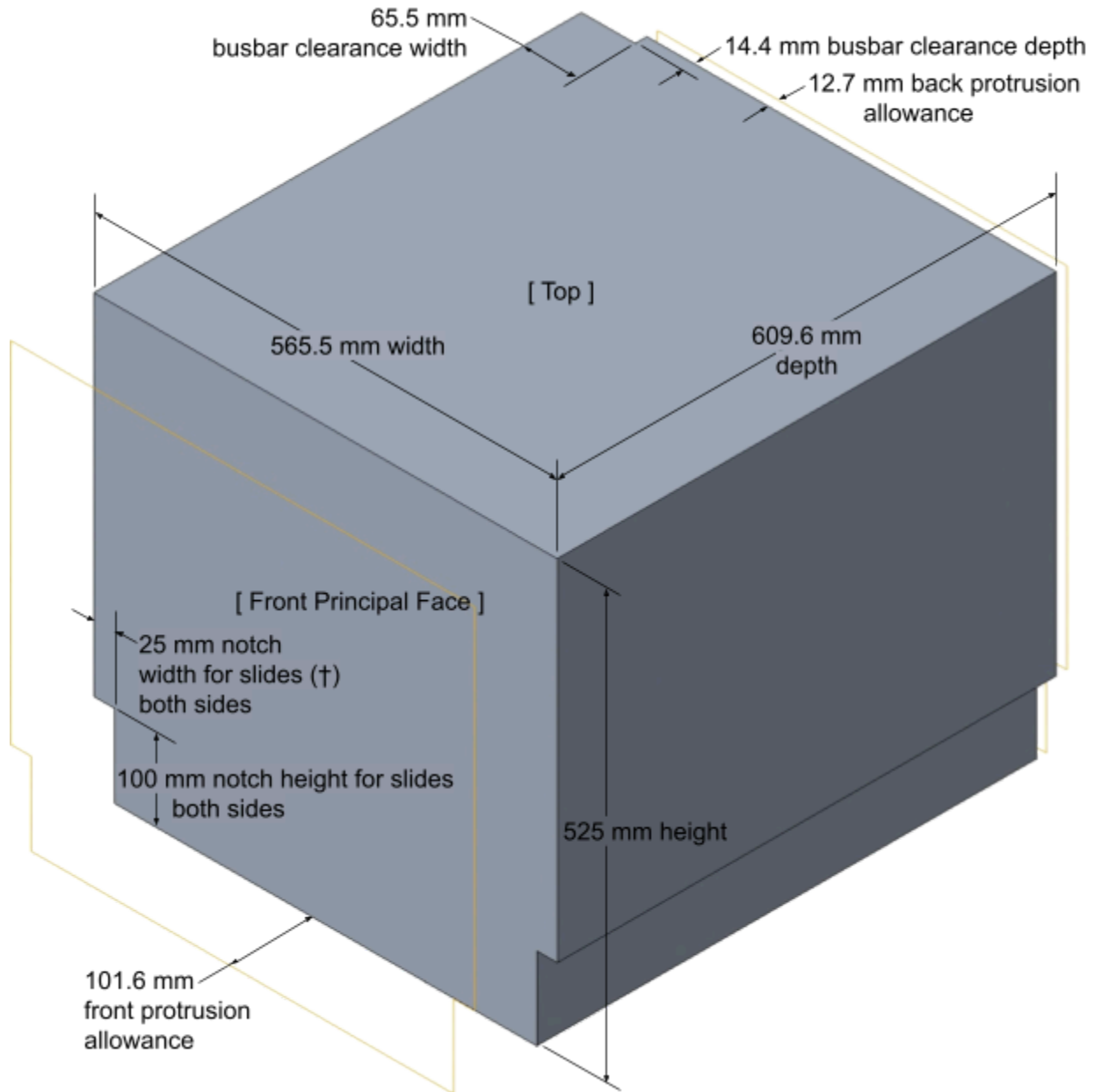


Figure 7.5-1: Brazos chassis keep-in volume with exclusions and allowances

The 48V busbar mating power connector shall be located on the back face of the busbar clearance notch, which is highlighted with blue tint in the following [Figure 7.5-2](#), with the center plane of the busbar interface as shown, 33.99mm from the side of the keep-in volume. The power connector should be placed as low as practical in the assembly, close to the elevation of

the slides, so that relative translation of the connector is minimized during transportation shock & vibration events. As the slides are developed, we can consider reducing the 25mm notch width for slides if that enables lowering the power connector further (modifies dimension with (†) in [Figure 7.5-1](#)).

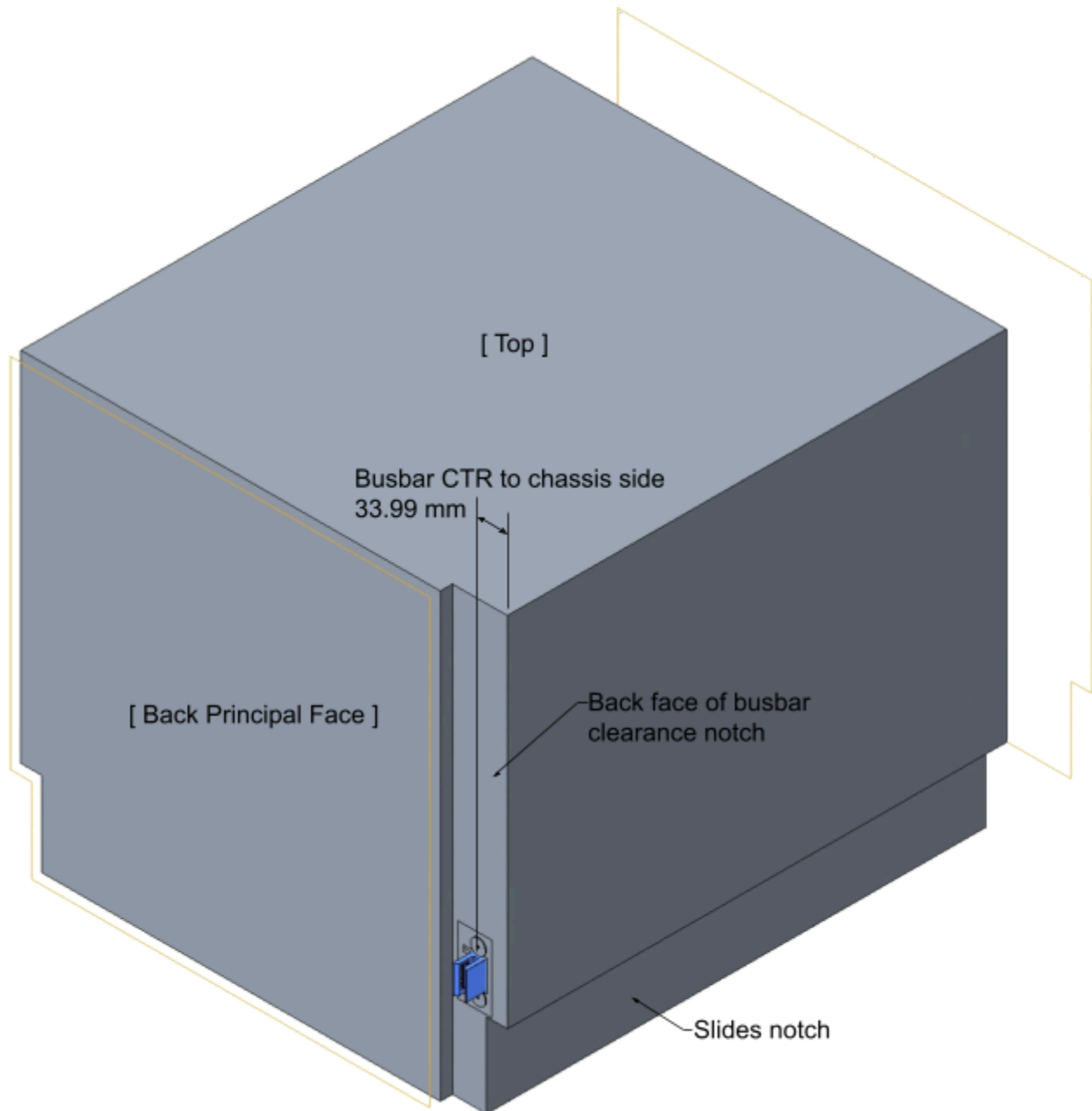


Figure 7.5-2: *Brazos chassis volume with power connector location*

Features specified later in Figures 7.6-x may override/extend limits of Figures 7.5-x. Actual total depth is 813.7mm. This includes individual exceptions for fan module handles beyond the back protrusion allowance and example FD83 ports beyond the front protrusion allowance.

7.6 Design of Liquid Interconnect for Chassis Front

This section is broken into two, the first to cover the minimum protrusion of main liquid connections for compatibility with possible rack deployments of Brazos chassis installed in the same rack as IT loads. The second section is for a customization of the elbow shaped plumbing segments to optimize the assembly for 3x Brazos installed in the same rack with IT load equipment to be installed in a separate rack. The full chassis design is to be capable of the first situation described here, and enabling the second situation is to be accomplished by only changing the elbow segments of plumbing identified there.

7.6.1 Liquid Interconnects for Minimal Protrusion

As noted in the [Liquid Interconnects](#) section, one example of the liquid interconnect at the Brazos chassis is the Danfoss FD83 style coupler ([vendor datasheet](#) example). These couplers, and the hoses from the rack manifolds that connect to it, must stay within the 101.6 mm (4 inch) front protrusion allowance identified in [Figure 7.5-1](#). These connections must be able to go to rack manifolds on either the left side or the right side of the chassis, so they need to exit the chassis at the lateral center, and they must be right-angle couplers (or couplers on right-angle fittings) which can also swivel at least 180° to be able to point either to the left or to the right as shown in the following [Figure 7.6.1-1](#). Vertical location of the right-angle fittings exiting the front face of the chassis is also shown in [Figure 7.6.1-1](#) with dimensions relative to the bottom surface of the keep-in volume. The right-angle fittings must have a tight enough bend such that the distance from the center of the chassis to the right-angle fitting for rack manifold to the side of the chassis can be less than 305.75mm. The location & design of other front-accessible FRUs must also be compatible in that access to them is not blocked by the possible hose path with the hoses connected.

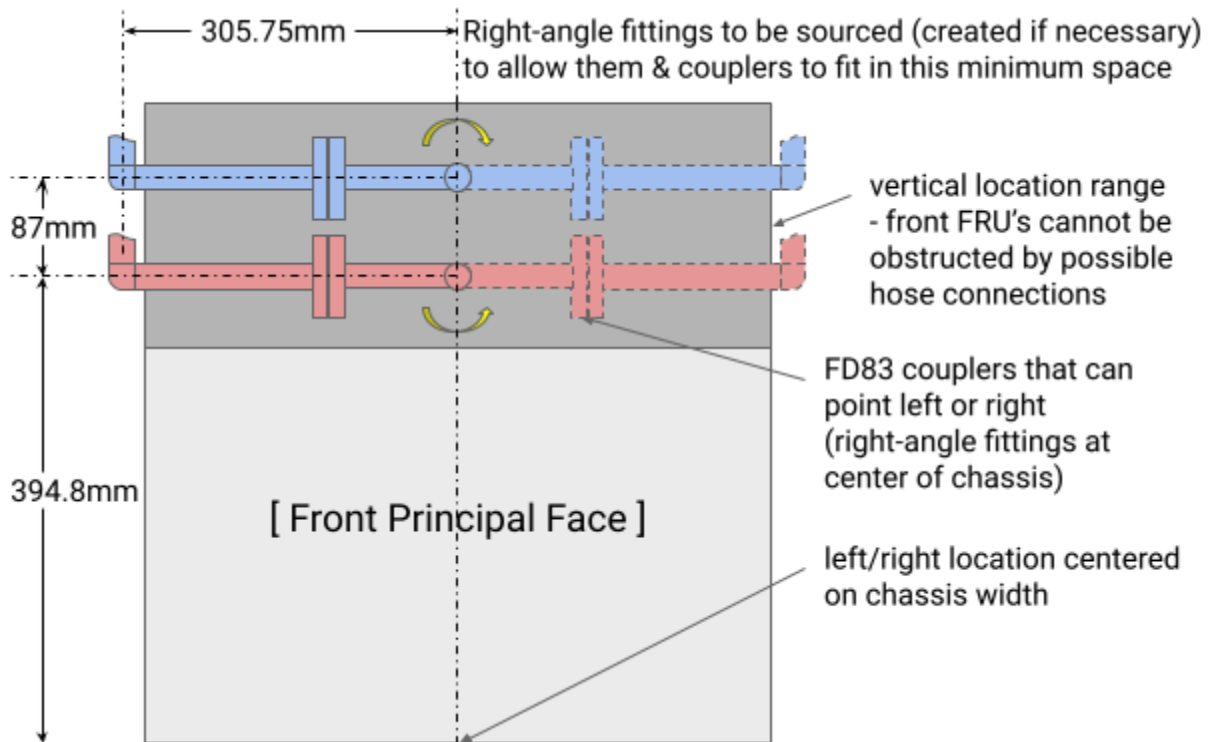


Figure 7.6.1-1: Brazos chassis front main liquid interconnect constraints. The Danfoss FD83 couplers are referenced as an example of a coupler/liquid interconnect.

The front-back location of the right-angle elbows for the liquid connector, for example, the Danfoss FD83, port locations is to be 643.1mm forward of the notch in the back of the chassis keep-in volume for the busbar clearance & chassis-stop. In general, the quick disconnect coupling must stay within 678.9 mm. This is described below in [Figure 7.6.1-2](#), and also includes the distance from the Front Principle Face of Keep-in Volume as a reference.

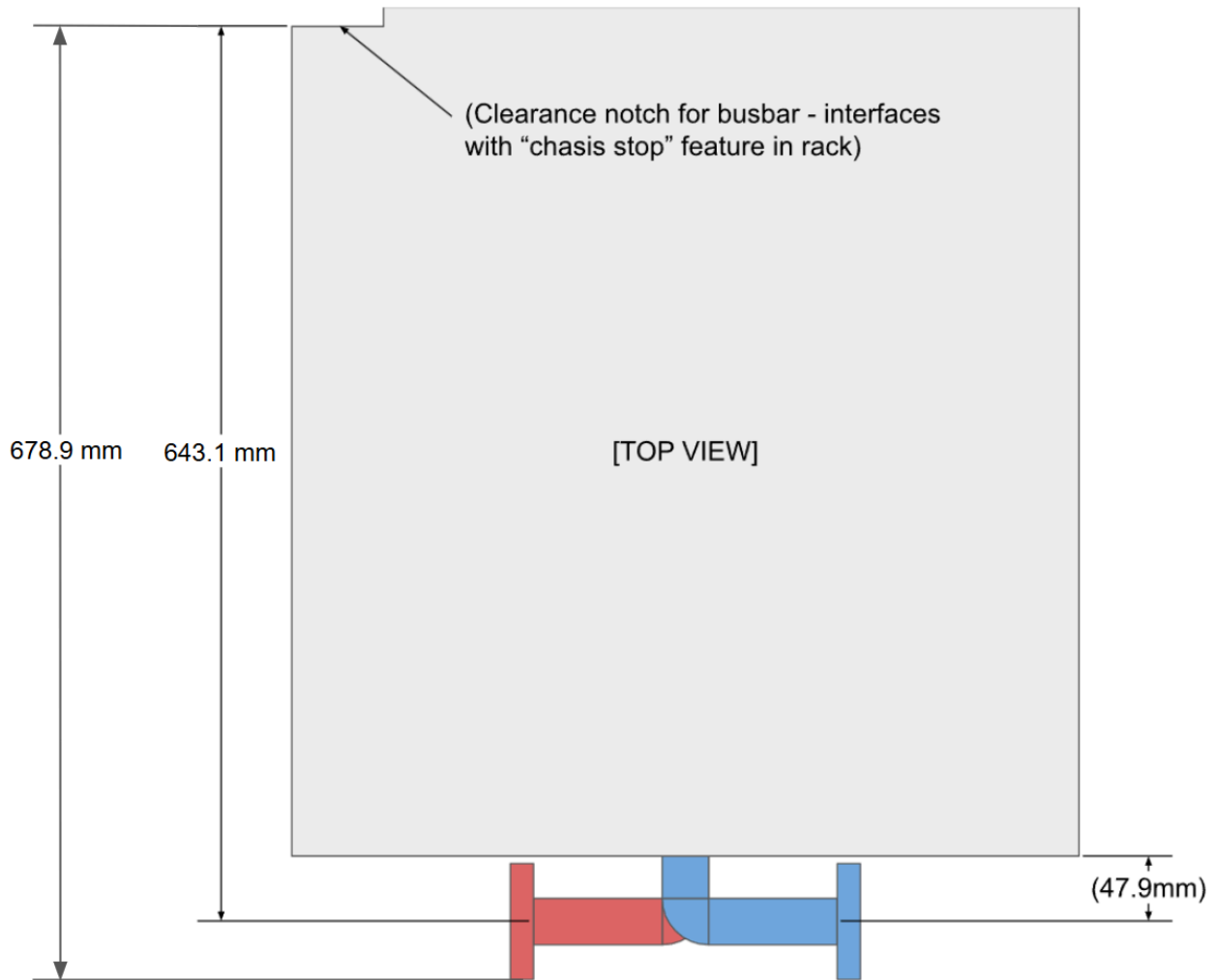


Figure 7.6.1-2: *Front-Back location of main liquid interconnects.*

The right-angle elbow exiting the front of the chassis for the example FD83 couplers shall resemble what is described in [Figure 7.6.1-3](#) below. The longitudinal (front-back) offset and the lateral offset shown are what shall ship with the unit. Alternate variations of these elbows may be fabricated in the future for use in various rack assembly designs to be compatible with the unique constraints of the rack manifolds in each rack assembly design.

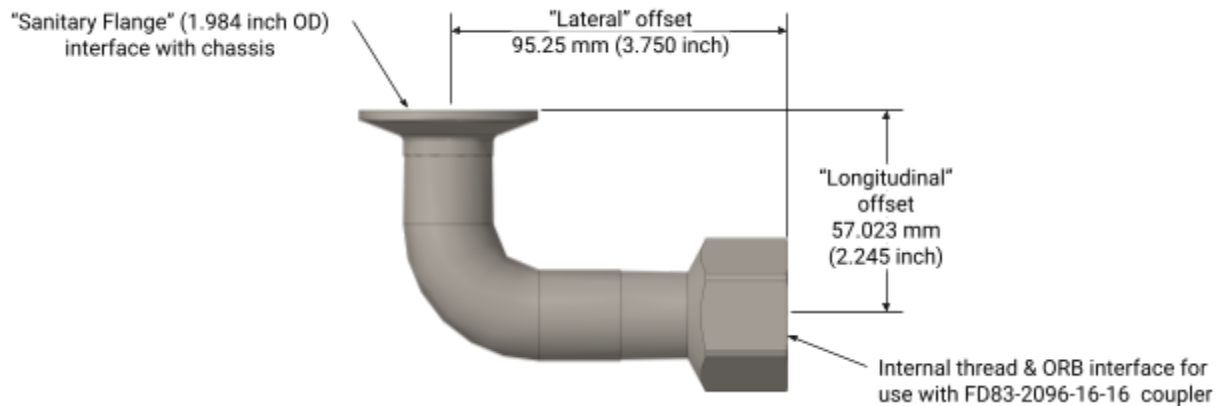


Figure 7.6.1-3: Right-angle elbow for example FD83 coupler attachment

7.6.2 Liquid Interconnects Optimized for 3x Brazos in 1 Rack

To accommodate 3x Brazos chassis within one rack, and more particularly to accommodate the rack manifold assembly for the same rack, the elbow fitting described in [Figure 7.6.1-3](#) must be replaced with a new elbow fitting which results in the following location and orientation of the couplers. While the elbow is in the horizontal plane, while viewed from the top, the center of the mating interface of the coupler (for example the FD83 connector) is to match what is described in [Figure 7.6.2-1](#). Note that this customized interconnect exceeds the 101.6mm (4 inch) protrusion allowance identified in [Figure 7.5-1](#), and since this geometry is specified here, it is a use-specific allowance to the original keep-in volume.

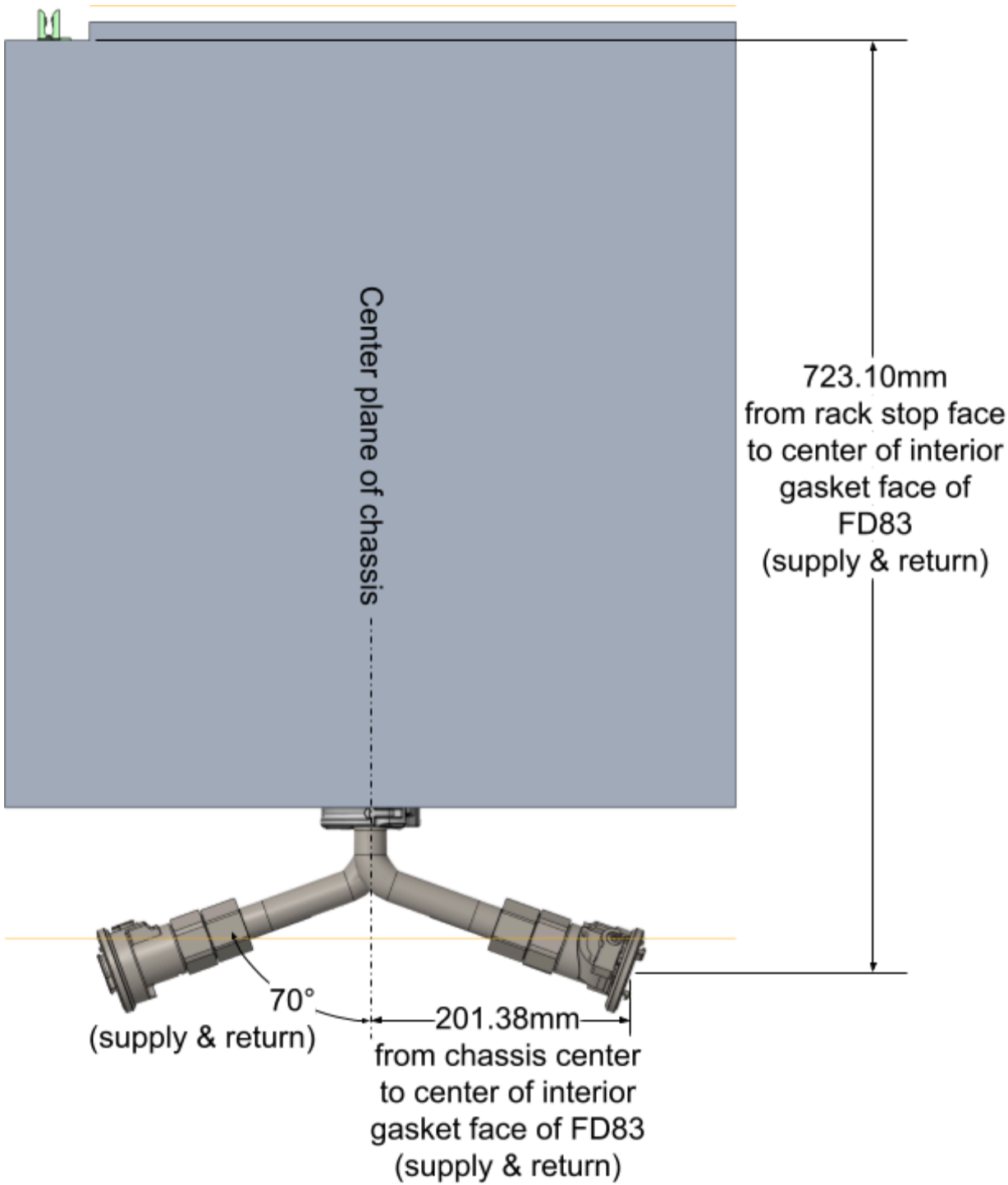


Figure 7.6.2-1: Customized Elbows of the example FD83 Connections for 3x Brazos in 1 Rack

7.7 Additional Provisions of Front Protrusion Allowance

Because the liquid interconnects (for example, the FD83 couplers) and hoses occupy space in the upper half of the front face of the Brazos chassis, the front protrusion allowance below the liquid interconnects may be occupied as follows. FRU modules and supporting chassis structure may extend forward of the front principal face by 76.2mm, and up to an additional 25.4mm may be occupied by handles, latches and other fasteners. However, the plane of any bulkhead connector interfaces shall be coincident with the front principle face. The slides for mounting the chassis may also extend forward of the front principle face by that 76.2mm allowance. These regions within the allowance are described pictorially in the following [Figure 7.7-1](#).

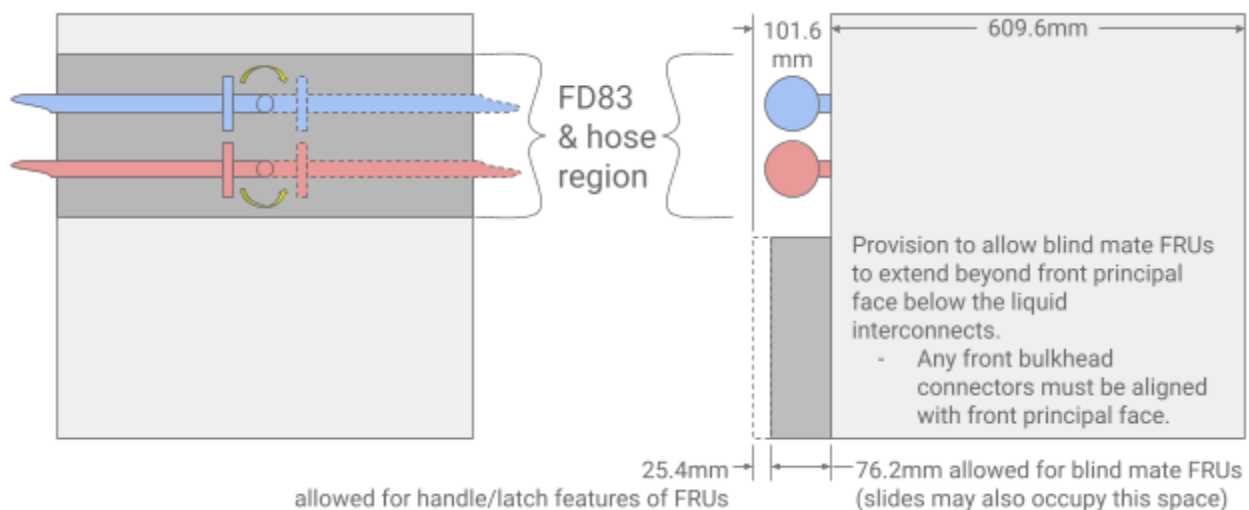


Figure 7.7-1: Front Protrusion Allowance Provisions shown with the example FD83 liquid interconnectors

7.8 Slides for Mounting Brazos Chassis in a Rack

7.8.1 Slide Design Requirements

Slides must support all indicated rack types and be multi-sourced. Adapt slides with brackets as needed. The default slide kits shall be able to install into the SH rack with mounting and opening cross section as described in [Figure 7.3.2-1](#) and [Figure 7.3.2-2](#). Adapter brackets are to be designed and available to order for installing into the Z2 rack with the mounting and opening cross section described in [Figure 7.3.1-2](#) and [Figure 7.3.1-3](#).

While carrying a full load, slides must operate at less than 15 pounds-force sustaining push and pull force and require less than 15 pounds-force for two hand operation or 10 pounds-force for single hand operation. When fully extended, slides must not sag more than 2.2 degrees.

Slides must extend far enough to replace rear FRUs outside of Rack Bay (914.4mm / 36 inches). Slides must allow separating into outer and inner pieces for ease of chassis installation/mounting into the rack. The inner-most slide sections are to be attached to the chassis using removable screws to facilitate removal of a chassis from the rack in case separating the slide segments becomes difficult due to challenges with an available lift assist holding the unit at the right height and level.

Slides must meet safety requirements in [Table 7.8.1-1](#) below.

Test	Simulation	Criteria	Pass/Fail
Downward Force - 180 lb (800 N) static load for 1 min	Person falling/stepping on a loaded shelf	No risk of injury to the person - Shelf does not collapse - Rack does not tip	Slides still function as intended at least 1 more cycle
Downward Force - 300 lb (1334 N) static load for 1 min	Person falling/stepping on a loaded shelf	No risk of injury to the person - Shelf does not collapse - Rack does not tip	For Pass, slides can bend/deform as long as they do not collapse. No functional requirement after test.
End Stop Integrity - 250N Static Pull for 1 min (repeated 10x)	Person pulling on a shelf that has reached its extended limit.	No risk of injury to the person Shelf does not become dislodged from the rack	For Pass, slides can bend/deform as long as they do not collapse. Slides must be able to operate 1 more cycle, or accept 25 lb force applied at the center of the front without falling off or creating risk of injury to the person.
Lateral Push - 250N Static Push for 1 min (right/left sides)	Person leaning on either side of an extended shelf	No risk of injury to the person Shelf does not become dislodged from the rack	For Pass, slides can bend/deform as long as they do not collapse. Slides must be able to operate 1 more cycle, or accept 25 lb force applied at the center of the front without falling off or creating risk of injury to the person.
Rack Tip Test - unit extended on slides (interlock to prevent more than 1 out at a time)	Single unit installed in otherwise empty rack	No risk of injury to the person	Rack internal weight or additional bracing prevents tipping when more unit is fully extended

Table 7.8.1-1: Safety Requirements for Slides

In addition to the slides for mounting the chassis into the rack, securing features must be included to adequately support & restrain the chassis in the rack during transportation shock and vibration as well as seismic events. It is preferred that the securing features have a tool-less interface to release the chassis to allow it to extend on slides and to secure the chassis after it is retracted. If threaded fasteners are used in this interaction, they must be captive and accept a size #2 Phillips driver. Actions for releasing & re-engaging these securing features must meet ergonomic requirements. These securing features must not extend any wider than the SH rack payload opening width (571.52mm / 22.5 inches).

During all shock & vibration test inputs, including seismic, slides must remain locked in their position. Slides must continue to meet requirements after 500 cycles while loaded at full product weight (including liquid) and may be susceptible to ongoing reliability testing. Tolerance analysis must be complete to ensure the system will keep slides within their operating range to prevent compression or tension.

7.8.2 Interlock Requirements for >1 Chassis Mounted on Slides

An Interlock mechanism to prevent more than one Brazos chassis from extending forward at the same time is required for rack designs which may have multiple Brazos within one rack. The primary reason for this requirement is to eliminate the risk of rack tipping as a result of multiple units being extended beyond the front of the rack base. This is a separate and additional feature than the securing features mentioned previously because an operator may leave those securing features disengaged and try to short-cut work by trying to have multiple units extended at the same time without realizing the risk of tipping.

The Interlock mechanism must function such that in its resting position (spring-loaded or affected by gravity), any one Brazos chassis can move forward on its slides after disengaging the securing features. As one chassis moves forward, the interlock mechanism should be automatically activated (e.g. moved up or down) causing similar design pieces placed adjacent to the other Brazos chassis to be positioned such that they prevent any other Brazos chassis from being able to extend on its slides.

The Z2 rack can allow multiple Brazos chassis to be stacked vertically as shown in the following [Figure 7.8.2-1](#) (see also 3D CAD file “0design_brazos_rack_interface_z2x2_2024-03-06.stp” - refer to CAD available from OCP), which shows 2 units stacked vertically and the pattern could be repeated to stack 3 vertically. The SH rack is configured such that it has 2 columns, so Brazos could be arranged side-by-side as shown in the following [Figure 7.8.2-2](#) (see also 3D CAD file “0design_brazos_rack_interface_shx2_2024-03-06.stp” - refer to CAD available from OCP). The first planned configuration to deploy will stack 3x Brazos chassis vertically within a Z2 rack which has customer supplied adapters & a repositioned busbar to be equivalent to the opening of a SH rack, as described in [Figure 7.8.2-3](#). The expectation for multiple units in one

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rack is limited to a) 2x in SH rack consisting of 1x unit in each column at the same elevation near the bottom of the rack, and b) 2x or 3x stacked vertically adjacent within a Z2 rack.

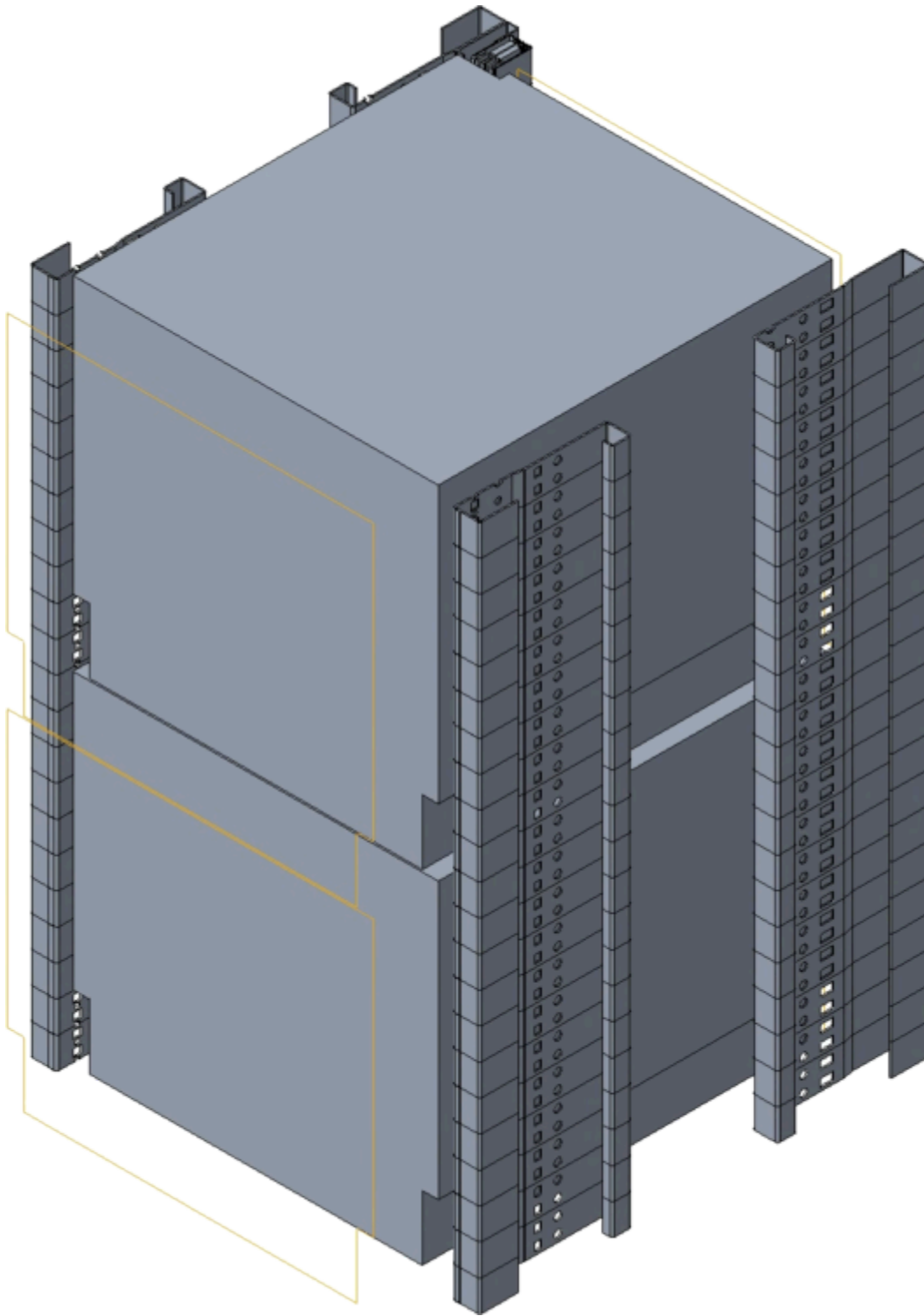


Figure 7.8.2-1: *Rack Interface for Z2 x 2 Brazos*

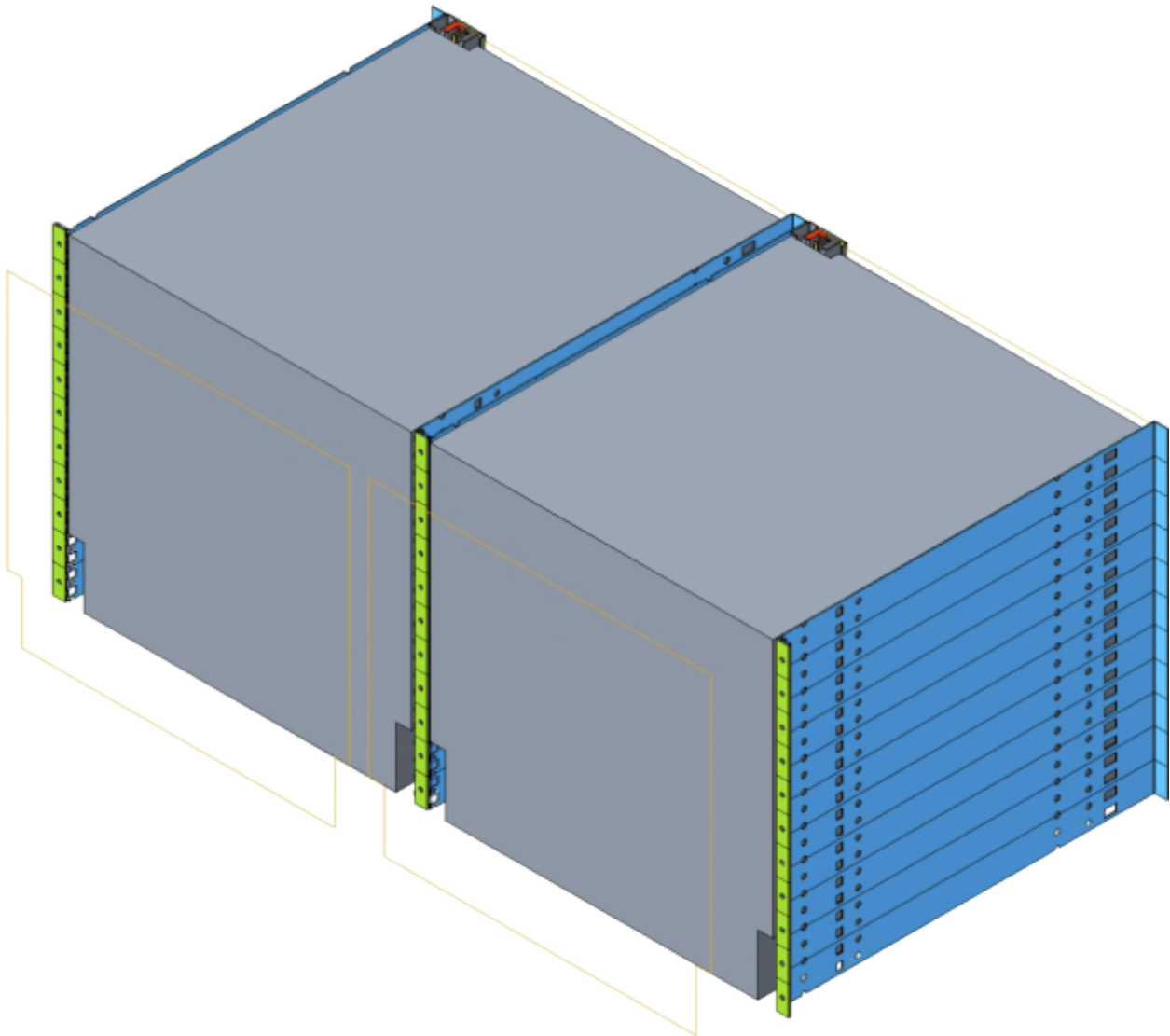


Figure 7.8.2-2: *Rack Interface for SH x 2 Brazos*

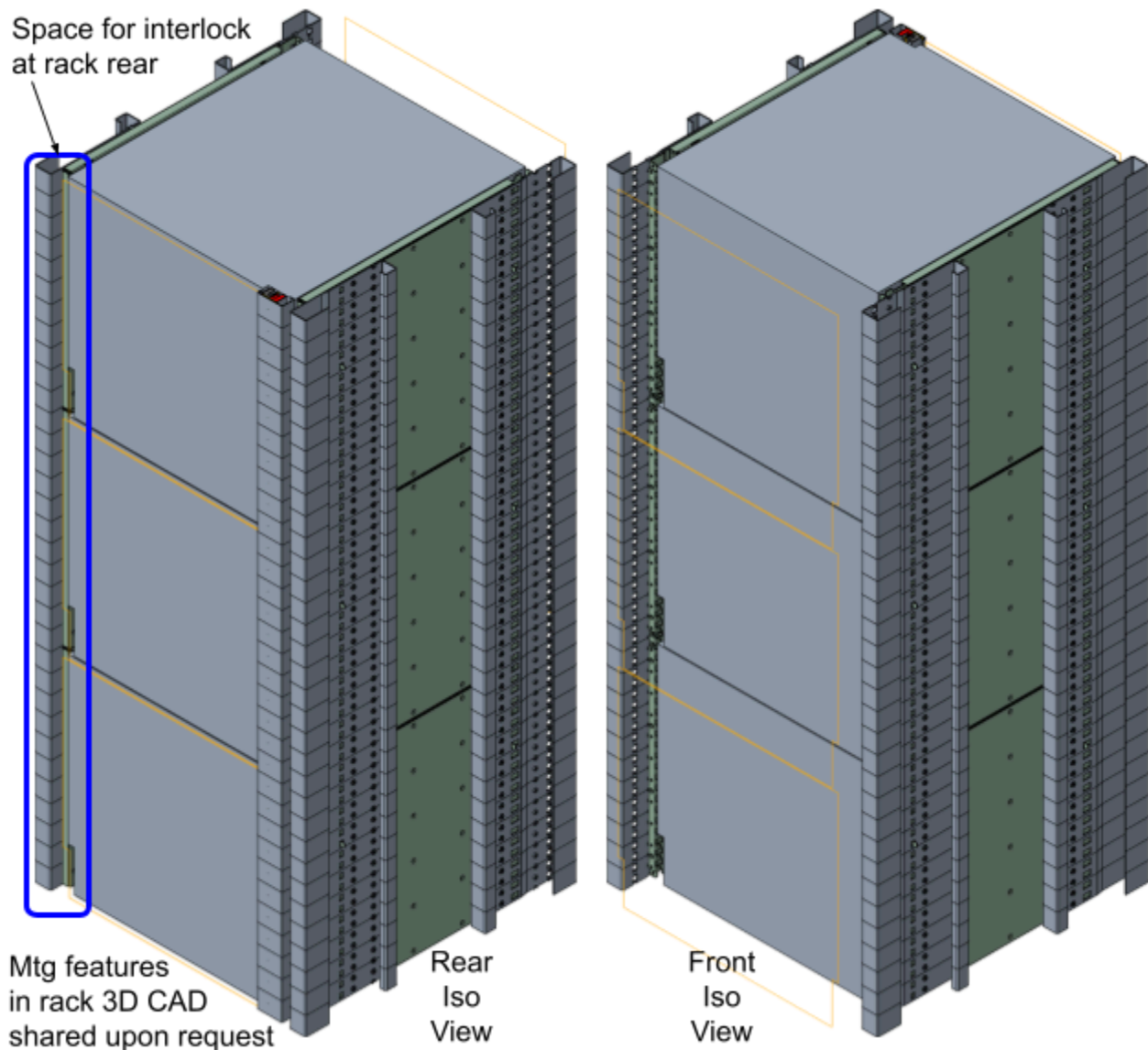


Figure 7.8.2-3: Rack interface for 3x Brazos in Z2 converted to SH payload opening

For a SH rack with 2x Brazos side-by-side, the interlock can consist of a to-be-designed mechanism which can be placed on the center column of the rack between the two units (at the elevation of the slides). This mechanism could be turned or otherwise biased to one side so that it allows one unit to extend and prevents the other unit from extending. It would need to be placed at the elevation of the slides so that with the unit fully extended the slides are in the way of moving the mechanism to unblock the second unit. The Brazos chassis & slides design shall not prevent mounting such an interlock mechanism to the center column of the SH rack.

For a Z2 rack with multiple vertically stacked Brazos chassis, an interlock shall be designed and provided to operate with 3x Brazos in a Z2 rack converted to SH payload opening, as described in [Figure 7.8.2-3](#). The interlock mechanism shall be located at the back of the rack along the side opposite the busbar, and shall attach to the main frame of the rack (mounting hole locations provided in 3D CAD model of the rack). The interlock mechanism shall engage a catch feature which shall be included on the back face of the Brazos chassis. The interlock design shall meet the strength requirements described in [Table 7.8.2-1](#).

Test	Simulation	Criteria	Pass/Fail
Interlock Robustness - 250N Static Pull on locked shelves with one chassis extended on slides (repeat for each chassis)	Person attempting to pull out 2nd chassis when a 1st chassis is already extended (loosened screws on the chassis to rack mounting/securing brackets)	- No risk of injury to the person - Second drawer cannot be pulled out - Interlock mechanism is not damaged	For each scenario of the 1st extended chassis being in the top, middle, and bottom location in the rack, neither chassis in the other two locations can extend forward. Cycle through all 3 scenarios, repeating 10 times.

Table 7.8.2-1: Interlock Strength Requirement

7.8.3 Chassis Labeling for Safety Considerations with Slides

The Brazos chassis is to include informational labeling warning of risks associated with products mounted on slides, including instructions on how to avoid those risks. Label content shall include the following content:

- WARNING (large font and preceded by symbol of exclamation point within a triangle)
- TO AVOID RACK TIPPING AND THE RISK OF INJURY OR PRODUCT DAMAGE,
- DO NOT EXTEND MORE THAN ONE CHASSIS ON SLIDES AT THE SAME TIME
- DO NOT STAND, SIT, OR CLIMB ON ANY DEVICES ON EXTENSION SLIDES
- DO NOT APPLY ANY WEIGHT OR DOWNWARD FORCE TO A DEVICE ON SLIDES
- DO NOT MOVE A RACK WITH A DEVICE EXTENDED ON SLIDES
- SECURE ALL DEVICES IN RACK WITH INCLUDED MOUNTING SCREWS BEFORE EXTENDING ANOTHER UNIT OR MOVING THE RACK

Labeling with the above described content is to be included on the top cover and also on the left and right sides of the chassis.

7.9 Design for Unpacking and Transfer to a Lift Assist

The designer/manufacturer/supplier of the Brazos product shall include in the design any necessary handles and other brackets to facilitate manipulation of the assembly to aid in installation into the rack.

The supplier shall provide a packaging solution for shipping a Brazos CDU chassis to the rack integrator, and also to a datacenter in the event a unit needs to be swapped. An “RMA Kit” consisting of all needed packaging and additional support materials (such as shipping brackets) for the customer to return a failed unit to the supplier for failure analysis and/or replacement. The packaging solution shall fit on a 48 inch x 40 inch pallet.

Deployment sites will not have access to a crane-like overhead suspension (cables or chains) lift assist, but will have lift assist with an adjustable horizontal platform which can only support the product from below, such as the [ServerLIFT SL-500X](#). The design of the packaging, for shipping a Brazos CDU chassis from the supplier to the rack integrator, must enable a single operator to transfer the unit from the packaging to the horizontal lift platform. The force to push or pull a unit from the packaging onto an aluminum horizontal platform shall be designed to be less than 15 lbf, and verified to be less than 29.5 lbf.

To achieve this low frictional force, possible design solutions include, but are not limited to, the following ideas.

- Integrated or removable rollers on the bottom surface of the chassis.
 - If integrated, the rollers must fit within the chassis keep-in volume
 - If removable, they must come off as 1 assembly once the chassis is supported by the slides in the rack in the extended position. In the event a Brazos chassis needs to be removed & returned, the bottom roller assembly must be able to be added back onto the chassis while supported by the extended slides.
- Removable rollers attached to the sides of the chassis in place of the slides
 - Side-attached rollers must be able to be removed without any additional external lifting of the product to remove weight from the rollers, so that the rollers may be removed and the internal portion of slides may be attached.
 - Side-attach rollers must also be able to be added to a chassis on a lift assist (for example, after removing from a rack) for transferring back into packaging.

7.10 Shock & Vibration requirements

Supplier is to design & test the Brazos system (full assembly and FRU modules where applicable) to meet the performance requirements during “operational” environments and after each of the “non-operational” and “transportation” environments specified as follows.

7.10.1 Operational Shock & Vibration

Operational environment tests are to be done with the full product installed on fixtures that represent the rack mounting interface. The fixtures are to include the interface to a section of the busbar. Electrical resistance across the busbar connection is also to be measured during these tests. Vertical or normal gravity direction is aligned with the “Z” axis identified below, the X and Y axes correlate to the front-to-back and side-to-side directions, respectively.

7.10.1.1 Operational Vibration - Sine Sweep

Sine Sweep: 0.12G X, Y axes, and 0.17G Z axis, 5-500-5 Hz, 1 oct/min, 5 Sweeps

7.10.1.2 Operational Vibration - Random

0.16 Grms, $1.05 \times 10^{-4} \text{ G}^2/\text{Hz}$ 5 to 250 Hz, 15 minutes duration, X, Y, Z axes

7.10.1.3 Operational Shock

3.5G 11ms half sine, 10 +/- pulses, X,Y,Z

7.10.1.4 HALT-like interconnect robustness

Observe & note soft interrupts and ultimate failures for each of the following levels.

- G levels: 10, 20, 40, 60, 80, 100, 150, 200 (stop at failing G level);
- 2ms half sine, 1 pulse, Z-primary, X, Y

7.10.2 Non-Operational and Transportation Vibration

These non-operational tests are to be done in 3 configurations, bare product, packaged, and installed in-rack. The in-rack tests are to be performed in a customer supplied rack.

7.10.2.1 Bare Product

Bench Handling Drops

Bench Handling represents events which may occur while items may be handled without packaging during installation, removal, or other handling. Drop testing to be done for the full assembly as well as individual smaller FRU modules. Each test item is to be oriented so that it ends up with the principal resting face down.

For test items 45.4 kg (100 lbs) or less, the measured drop height is to be 76 mm (3 inches).

For test items greater than 45.4 kg, the measured drop height is to be 25 mm (1 inch).

Test items are to be dropped to land as follows: Flat on bottom face, 4 bottom edges, 4 bottom corners. Setup for the edge and corner drops is described in the following [Figure 7.10.2.1-1](#).

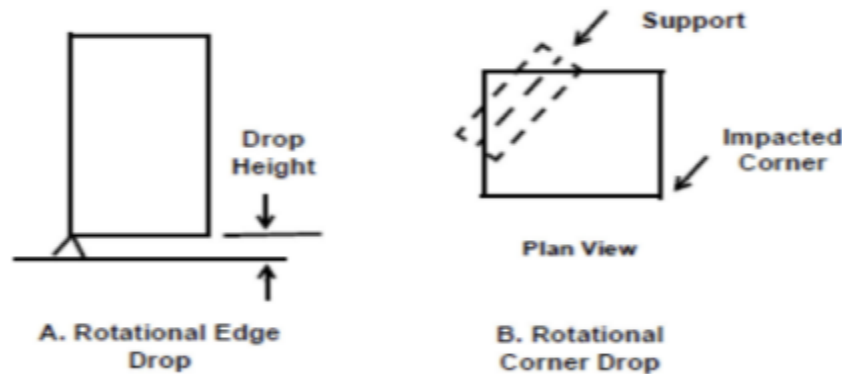


Figure 7.10.2.1-1: Setup for edge and corner drops

Non-operational Sine Sweep

Non-Operational Sine Sweep is to be applied with the full assembly installed in a fixture representing the rack mounting.

- 0.2G X,Y,Z Swept Sine 5-500-5 Hz, 1 oct/min, 1 Full Sweep (to identify modes)
- 0.3G X,Y, 0.6G Z Swept Sine 5-500-5 Hz, 1 oct/min, 5 Sweeps (for robustness)

7.10.2.2 Packaged Transportation Testing

Transportation Random Vibration

Items shipped on a pallet, e.g. full assembly and FRU items in bulk packaging, may be tested on a pallet for one orientation. Items that may ship without a pallet must also be tested while oriented in the other 2 orthogonal axes. The random vibration environment to apply is per ASTM D4169 section 12.4, Assurance Level 2

- 1 hour of “Truck” vibration
- 2 hours of “Air” vibration

Single Unit Drop Tests

Single Unit Packaging tests apply to items which may ship without a pallet.

- Perform drops depending on packaged weight per the height, orientation, and sequence defined for Assurance Level 2 in ASTM D4169 Section 10.2.3

For the full assembly, if it always ships on a pallet, and if it is enclosed in some amount of packaging before being placed on the pallet, or the item may be removed from the pallet before opening the packaging enclosure, apply the following reduced drop sequence.

- Perform a rotational edge drop for each of the 4 bottom edges from a 102 mm (4 inch) drop height. Setup per the Edge Drop shown in [Figure 7.10.2.1-1](#).

Palletized Drop Tests

Palletized testing applies to the Full Assembly as well as any individual FRUs shipped in bulk on a pallet. If FRUs were tested individually, the packaging for FRUs must be verified that they can

withstand the weight of other FRUs that may be stacked above it on the pallet during these drop tests.

If the pallet mass is 226.8 kg (500 lbs) or less, the measured drop height is to be 229 mm (9 inches). If the pallet mass is greater than 226.8 kg (500 lbs), the measured drop height is to be 152 mm (6 inches). Drop the loaded pallet as follows: Flat on bottom face, 4 bottom edges, 4 bottom corners. Setup for the edge and corner drops is described in [Figure 7.10.2.1-1](#).

7.10.2.3 In-Rack

These tests are to be performed with the full assembly installed in a rack. The rack to be used for testing is to be provided by the customer.

Uncrated In-Rack Testing

This testing is to represent events that may happen while handling a rack with the Brazos unit installed either at the integration site or the installation site. Perform the following tests with no coolant in the rack assembly and with all the plumbing in the rack filled with coolant.

- Threshold roll-off: while rolling at a speed of 853 mm/s (2.8 ft/s), drop off a 19 mm (0.75 inch) thick plywood.
- Threshold impact: roll the rack at 305 mm/s (1 ft/s) into a threshold that stops the rack.
- Stability (as shipped): tilt the populated rack 10 degrees toward each side to verify it does not tip over (with safety precautions to catch the rack if it tips more than 10 degrees)
- Stability (Chassis slides extended): With precautions to limit tipping, extend the top Brazos chassis on the slide mounts to the fully extended position. Tilt the rack forward 10 degrees and verify the rack does not tip over.
- Stability (Chassis slides extended plus force): With precautions to limit tipping, extend the bottom Brazos chassis on the slide mounts to the fully extended position. Tilt the rack forward 10 degrees, and apply a force of 180 lbs (800 N) at a location 62mm back from the front edge of the chassis top cover. Verify the rack does not tip over.

Crated In-Rack Testing

Use the shipping crate which the customer provided rack is delivered in. With the item to be tested installed in the rack, secure the rack in the shipping crate, and perform the drops as specified previously in the subsection [Palletized Drop Tests](#). Also perform vibration testing per what was specified previously in the subsection [Transportation Random Vibration](#).

7.10.2.4 Seismic

A seismic simulation test must be performed with a Brazos chassis installed near the bottom of the rack, in positions OU-4 to OU-14 (bottom 3-OU left empty).

Test Setup and Procedure

1. Reference Standards and Specifications
 - a. ASCE 7-16, Chapter 13
 - b. AC156: Acceptance Criteria for Seismic Certification by Shake-Table Testing of Nonstructural Components
2. Seismic Parameters
 - a. Table below summarizes seismic design forces and variables.

Site Variables				Accel Terms				Equivalent Static Force ¹	
$S_{DS} [g]^2$	$z/h [-]$	$I_p [-]$	$R_p [-]$	A_{FLX-H}	A_{RIG-H}	A_{FLX-V}	A_{RIG-V}	$F_p [g]$	$F_v [g]$
2.185	0.25	1.0	2.5	3.278	1.311	1.464	0.590	0.524	0.437

Table 7.10.2.4-1: Seismic Parameters

¹ Expressed in g terms, per ASCE 7-16

$$A_{FLX-V} = 0.67 \cdot S_{DS}$$

$$A_{FLX-H} = S_{DS} \left(1 + 2 \frac{z}{h} \right)$$

$$A_{RIG-V} = 0.27 \cdot S_{DS}$$

$$A_{RIG-H} = 0.4 S_{DS} \left(1 + 2 \frac{z}{h} \right)$$

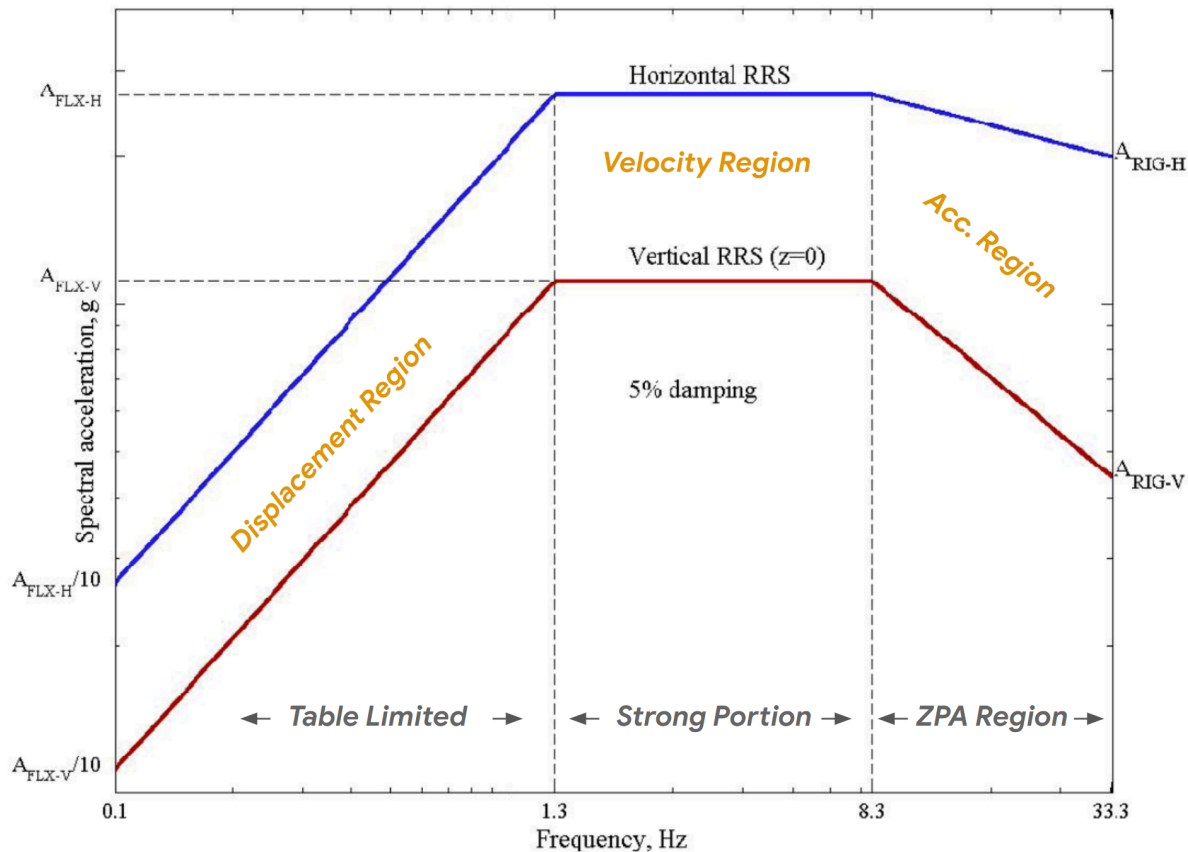


Figure 7.10.2.4-1: Required Response Spectrum (RRS) per AC-156. Normalized for the Component

3. Pre-Test Inspection

- a. Document the following pre-test inspection items in the final test report.
- b. Record the total mass of UUT.
- c. Visually check the overall unit for cracks, delamination, debonding, structural yielding, fastener, connectors, and caster integrity.
- d. Verify UUT mounting
- e. Ensure seismic bracket and unistrut bolt heads are marked after applying the specified bolt torque.
- f. Check the torque on the Left Wall, Right Wall and Shear Panel bolts. Ensure no bolts are loose.
- g. Perform electrical power verification.

4. Pre-Test Resonance Survey [0Hz to 50Hz minimum range]

- a. Resonance Search Test along the Z Axis
- b. Resonance Search Test along the Y Axis

- c. Resonance Search Test along the X Axis
- 5. Seismic Simulation Test
 - a. Perform a simultaneous triaxial test based on waveform generated per AC156 and the seismic design parameters provided in [Table 7.10.2.4-1](#) above.
- 6. Post-Test Resonance Survey [0 Hz to 50 Hz minimum range]
 - a. Resonance Search Test along the Z Axis
 - b. Resonance Search Test along the Y Axis
 - c. Resonance Search Test along the X Axis
- 7. Post-Test Inspection
 - a. Visually check the overall unit for cracks, delamination, debonding, structural yielding, fastener, connector, and caster integrity.
 - b. Document the status of seismic bracket and unistrut bolt head marks.
 - c. Check the torque on Side Wall, Mid Wall and Shear Panel bolts. Report if any bolts are loose or broken.
 - d. Perform electrical power verification.
- 8. Pass/ Fail Criteria
 - a. The UUT shall be visually examined and results documented upon completion of the multi-frequency seismic simulation tests performed in accordance with AC156 Section 6.5 to determine whether the UUT has adequate seismic capacity. The following conditions shall apply:
 - i. Structural integrity of the component attachment system shall be maintained. Limited yielding of the attachments shall be acceptable. Component design must ensure that the anchored UUT will not leave its mounting and cause damage to other building components or injury to personnel during the seismic event.
 - ii. Components Force-resisting System: Structural integrity of the component force-resisting system shall be maintained. Structural damage, such as limited yielding, to UUT force-resisting members is acceptable and structural members and joints not comprising the UUT force-resisting system shall be allowed minor fractures and anomalies.
 - b. Components with $I_p = 1.0$: At the completion of the seismic testing, the UUT does not pose a life or limb safety hazard due to collapse or due to major subassemblies becoming separated. Structural integrity of anchorage system and component force-resisting system shall be maintained. Structural damage, such as limited yielding, to UUT force-resisting members is acceptable and structural members and joints not comprising the UUT force-resisting system shall be allowed minor fractures and anomalies.

9. Test Report

A test report should be submitted with the following minimum requirements:

1. Test Equipment and Calibration Data
2. Seismic Parameters
3. UUT Description
4. Photographs and links to applicable videos of UUT (Pre/Post Test Inspection)
5. Shake-Table Test Data
6. Accelerometer Data Output: 0Hz to 50Hz
7. Displacement
8. Acceleration - Time Domain
9. Acceleration - Frequency Domain
10. Strain Gage Data Output
11. Triaxial Strain Data

8 Rack Manifold

8.1 Rack Manifolds for Z2 Rack - 3x Brazos in 1 rack

- Shall include a “Supply” (cold water) rack manifold assembly to be mounted on the front of the Z2 rack, on the right side (viewed from the front).
- Shall include a “Return” (warm water) rack manifold assembly to be mounted on the front of the Z2 rack, on the left side.
- Each rack manifold assembly shall provide 3x connections with quick disconnect style couplers to the 3x Brazos mounted in the rack, and combine the liquid flow to one coupler connection at the top of the rack for connecting to a neighboring rack of equipment to be cooled. An example of a quick disconnect, leak-free style coupler that can be used for data center applications is the “FD83” quick-disconnect coupling.
- Each rack manifold assembly shall include a passive air vent located at the top of the rack manifold attached with spill free quick-disconnect couplings.
 - The quick disconnect fitting attached to the air vent is to be a “socket” with British Standard Parallel Pipe (BSPP) G 1/4” thread.
 - The quick disconnect fitting attached to the block manifold is to be a “plug” BSPP G 1/4” thread.

The following figure is a concept sketch of what the rack manifolds assembly may look like. Note that the hose segments shown may not actually have the 90 degree bends, but that bend is to be accomplished with a liquid quick connect/coupler with a 90 degree hose barb fitting.

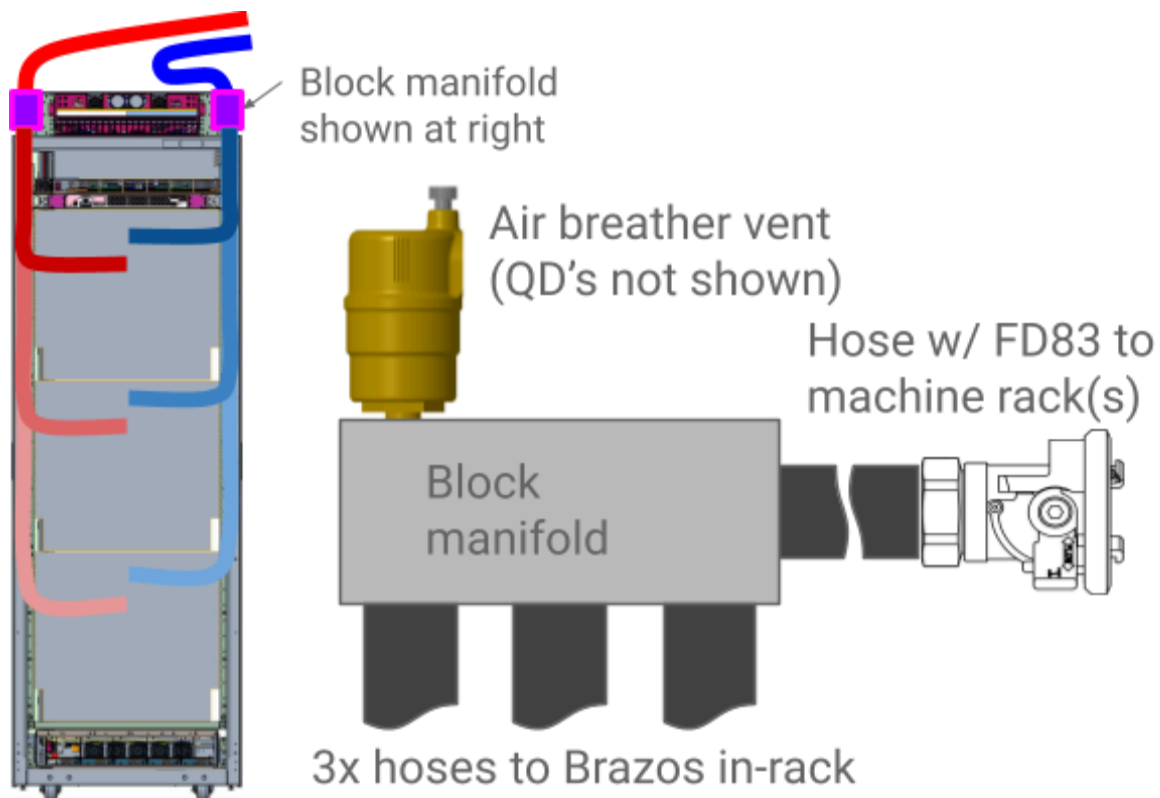


Figure 8.2-1: Rack Manifolds for 3x Brazos in Z2 Rack shown with the example FD83 quick disconnect coupler which is used for leak-free, quick disconnections in liquid cooling applications.

Overall height of the rack manifold installed on the Z2 rack, and with the air vent removed, shall result in the plug QD having a maximum height no greater than 86.2 inches. Total height including the air vent with QDs mated shall be no more than 90.3 inches. Additional details of the two rack manifold assemblies, including mounting brackets that double as a guard and a cable manager, are found in the 3D CAD models shared with this specification. A screen capture of a prototype stage 3D CAD design is included in [Figure 8.2-2](#).

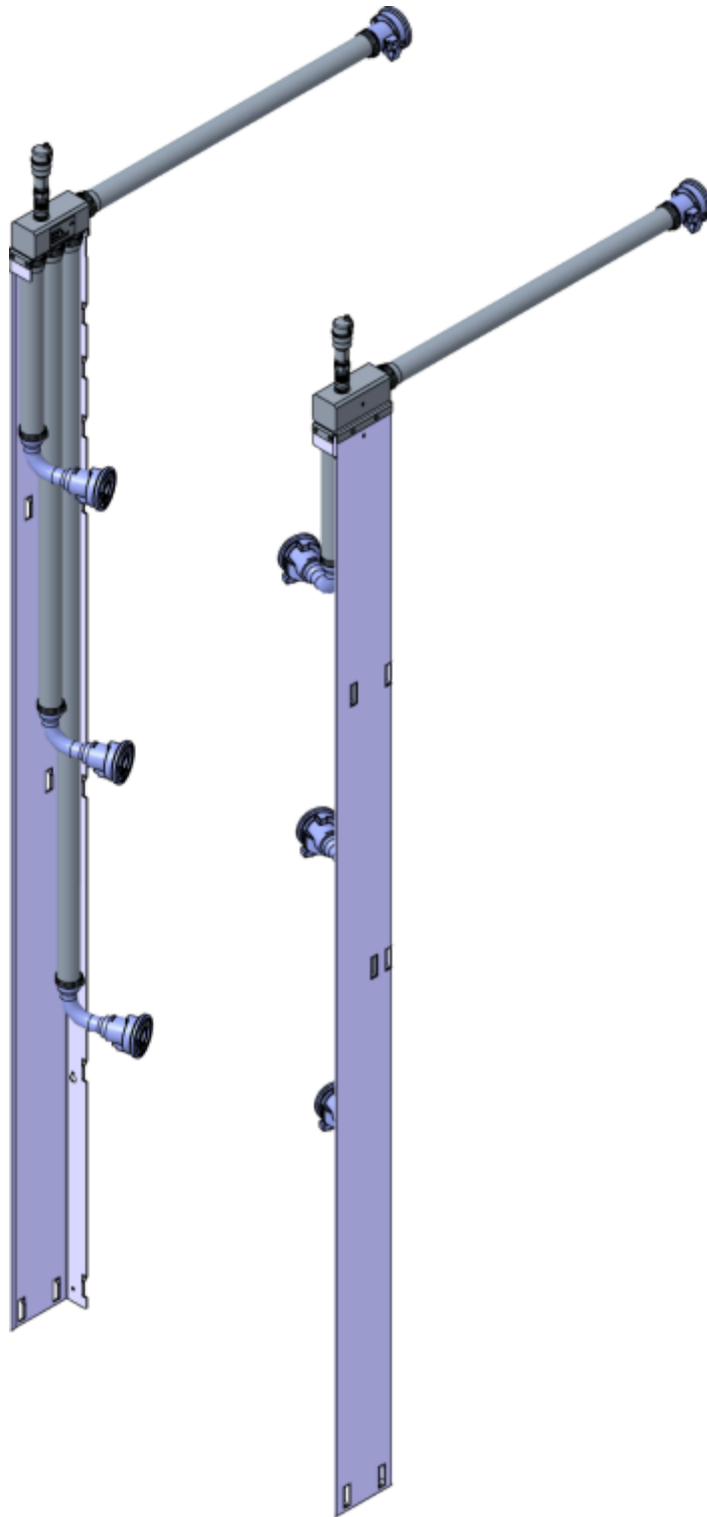


Figure 8.2-2: *Rack Manifold Assemblies for 3x Brazos in Z2 Rack*

9 Liquid interconnects

- The aCDU will connect to the rack manifolds with liquid quick disconnects. An example of a liquid quick disconnect is the Danfoss FD83.
- Interconnected rack manifolds in separate racks will connect with liquid quick disconnects. An example of a liquid quick disconnect is the Danfoss FD83.
- The liquid quick disconnect valves shall use the ORB thread type.

10 Coolant and materials compatibility

Wetted materials shall be compatible with DI water and PG25. Examples of compatible DI water and PG25 formulations are listed below:

- ChemTreat CL2002: 95% DI water, 5% chemical
- Garratt-Callahan 5666: 98% DI water, 2% chemical
- Veolia (Suez) SV5520: 97% DI water, 3% chemical
- DOWFROST™ LC 25 Heat Transfer Fluid

The system shall not contain nickel-plated brass.

11 Power & Electrical

11.1 Power consumption

- Electrical design of a single Brazos chassis shall be oversized to support 5000 W maximum.
- Total power consumption shall be limited to ~4000 W per Brazos chassis such that the total power for the Brazos rack with 3 chassis is ~12 kW. The total power consumption per chassis can be achieved with the following example pump and fans, respectively:
 - Up to 1.1 kW x 2 pumps from pump vendor Speck AY-4271
 - Up to 2 kW for fans from fan vendor EBM Pabst

11.2 Rack busbar

- DC: Nominal: +54.5V; Minimum: +40V; Maximum: +59.5V
- Duration: up to 120s at non-nominal voltage
- dv/dt: 30V/ms ramp up; 10V/ms ramp down
- All electrical components and payloads shall remain fully functional under the above static and transient voltage specs without impact on their designed performance (e.g., fans shall have sufficient PQ at 40V input)
- ORV2 input connector with sense (short) pin for hotswap enable

11.3 Protection

- Centralized fuse at power entry and distributed fuses for every FRU

- Centralized hotswap at power entry and distributed hotswaps/eFuses for every FRU
- Chassis and all conduct metal parts are to be properly grounded/bonded as required by the product safety standard.

11.4 Fans and pumps

- Connector with short pin for hot plug in/out
- Failsafe mode (default to max speed when PWM is open or short)
- No negative current flowing back to the front-end circuit at any time
- Low crest factor for fan input current (e.g., <1.5)
- Spin down times complies to safety team's requirement

11.5 Filtering

- 54V DC-link capacitor: roughly 0.5 mF/kW to 1 mF/kW; no capacitor before hotswap FET
- Onboard filter shall be properly damped with the busbar inductance considered (500-1000nH)

11.6 Diagnostic

- Dedicated front-panel LEDs to indicate power status (e.g., hotswap PG, fan/pump PG)
- Expose hotswap, fan/pump controller information to HMI

11.7 Component derating

- Follow IPC-9592B
- All major active/passive components shall have at least 20% derating to 60Vin (e.g., not OK to use a 65V-rated POL for 54V-to-3.3V)

11.8 Tray input hotswap

- An example of a hot swap controller is the ADM1272
- Enable and restart
 - Enable shall be controlled by power connector short pin
 - Remote power cycle capability (locally through HMI and remotely through the network-connected controller module.)
- Basic settings
 - UV falling: 39V; UV rising: 47V for >10us, no latch
 - OV rising: 61V for >10us; OV falling: 57V for >10us, no latch
 - Normal OC: 120-150% of peak current at 40Vin; timing based on FET SOA
 - Severe OC: 240-300% of peak current at 40Vin; response time < 2us; limited times of auto-retry
- FET

- 100V rated FET
 - Use a single FET's SOA to size the setting of start-up and short conditions
 - Tj less than 90C at full-load condition
- Telemetry
 - Expose Vin, Vout, Iout, Temp, Power to HMI
 - <2% voltage reading error
 - <3% power reading error at busy power
- FET health
 - Able to detect a FET drain-source short and not assert PG. Note: this detection must not be based on a current limit before HS startup
- Powergood
 - PG must be deasserted when a fault condition is detected (including FET health issue). PG must not be deasserted during noise events and immunity tests.
- Auxiliary circuit
 - TVS at input (junction capacitance of less than 1nF). An example of a TVS diode is the 5.0SMDJ60A.
 - Schottky diode at output
- Immunity
 - Line voltage steps within the operating voltage range due to power supply switching (45V to 55V, 30V/ms)
 - Surge immunity and compliance

11.9 Input fusing

- Voltage Rating: 80V DC minimum.
- Current rating: Choose based on payload power loading considerations.
- Interrupting Rating (AKA breaking capacity): The fuse must have an interrupt rating equal to or greater than the maximum available instantaneous short circuit current on the rack power bus providing power to the payload.
- Overload Considerations: The fuse shall have a minimum current threshold rating at which the fuse will open during overload conditions based on the time/current curve of the fuse without damage.
- Fuse Placement: Location of the fuse is to be as close to the input power connector as feasible.

11.10 PCB spacing

The high potential difference between the nominal 54Vdc POWER nets and RETURN/GROUND nets necessitates strict spacing requirements. This mitigates against CAF (Conductive Anodic Filament) failure and manufacturing defects causing a fire. The requirements around these high potential nets are:

- External layers (Top and Bottom of PCB) to have a minimum of 120 mils (3048 μm) clearance between signals of high potential difference if the signals are before the main board fuse at the input power connector.
- External layers (Top and Bottom of PCB): Minimum of 37 mils (939.8 μm) clearance between signals of high potential difference if the signals are after the main board fuse from the power input connector.
- Internal Layers: Minimum of 17 mils (431.8 μm) (copper to copper) /25 mils (635 μm) (via and through-hole) clearance between signals of high potential difference if the signals are before or after the main board fuse at the input power connector.
- In the Z-axis, high potential signals before the fuse must have a minimum 17 mils (431.8 μm) spacing or 3-ply prepreg/core. For signals after the fuse, minimum 3 mil z-axis spacing must be provided.

12 Serviceability

All maintenance, repairs and field replacements, including use of support equipment such as lift assists, must be serviceable within a horizontal distance of 48 inches in front of the rack in which the Brazos chassis is installed.

12.1 Swapability

- Front of unit service requirements:
 - Hot swappable pumps
 - Swappable redundant temperature & pressure sensors
 - Liquid connections for charging & draining
 - Hot swappable filters/strainers
 - May be redundant if there is 1 associated with each redundant pump and without other temporary bypass valves and plumbing
 - Live/online filter maintenance (i.e. shall not require system shutdown)
 - Live/online coolant refill (i.e. shall not require system shutdown)
 - Live/online liquid sample extraction (i.e. shall not require system shutdown)
 - Hot swappable control board
 - Hot swappable HMI
 - HMI may be allowed to have 2 possible mounting locations in order to minimize airflow blockage and to not interfere with main liquid connection routings.
 - Swappable power board
 - Swappable internal leak detection cable
 - Hot swappable external leak detection cable
 - The aCDU shall contain a drain valve for draining service
 - Swappable expansion tank
 - Enabled by a fitting which allows verification of proper attachment via

torque measurement, and without additional thread sealant (tape or liquid/gel) - ORB type fitting is preferred, alternates would need to be approved.

- Leak detection controller shall be accessible from the front of the rack, i.e. near the front of the chassis
- Hot swappable redundant fans with rack rear service
- The entire Brazos CDU may be hot swappable only if the IT equipment cooled by it is less than the capability of any other Brazos CDUs also connected on a shared manifold. Otherwise, if a Brazos CDU unit is required to be swapped, IT equipment cooled by it may need to be powered down because it would not have cooling.

12.2 Field replaceable units (FRUs)

- aCDU chassis (entire unit)
- Fans: each individual fan shall be a FRU, i.e. not a multi-fan tray nor all fans as one assembly. Fan FRU to include fan guards (internal and external)
- Pump assembly
- Control board
- Power board
- Pressure and temperature sensors
- HMI
- Rack manifolds
- Leak detection controller
- Leak detection cable
- Strainers/filters
 - The strainer/filter product package shall be given Part Number, Date Code, and Product description. Labeling is not required on the strainer/filter itself.
- All FRUs shall be serialized and labeled for traceability.

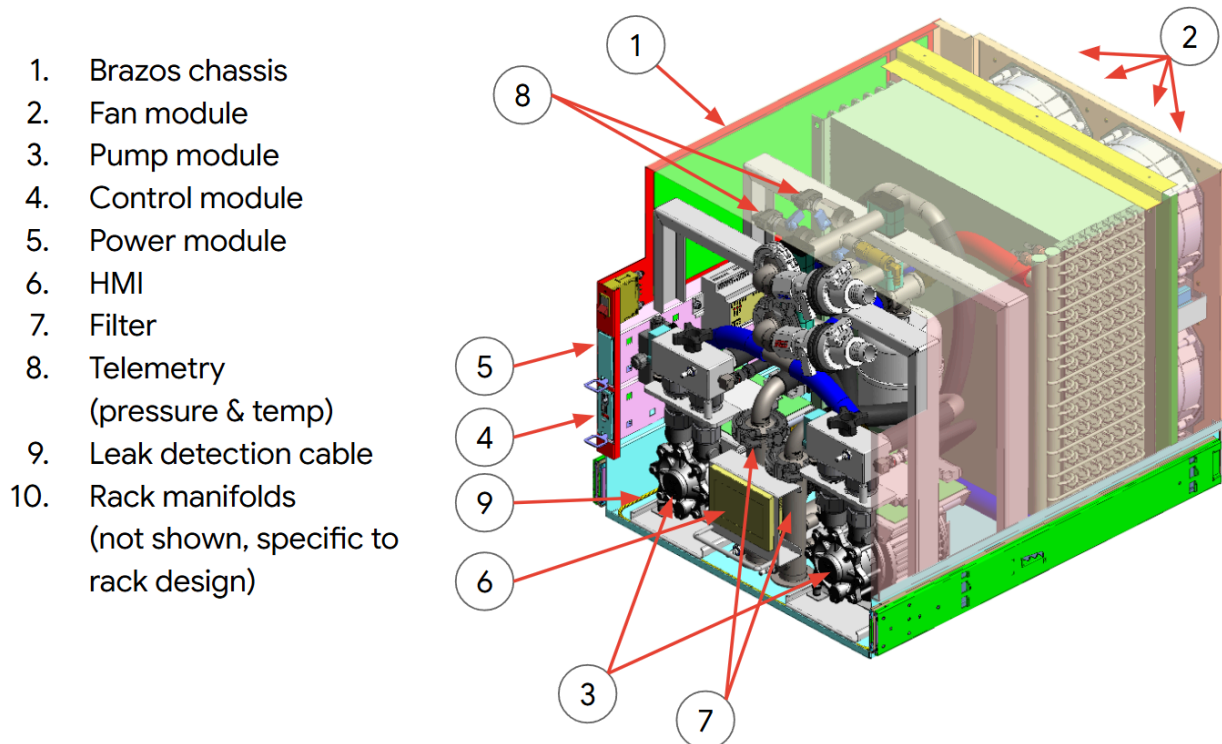


Figure 12.1: Brazos chassis with Field Replaceable Units (FRUs).

12.3 Mechanical

- Force limits for serviceable items
 - Full unit installation/removal
Push/pull forces to install or remove a full chassis into/from a rack shall be less than 15 lbf. For this force limit and other rack interface requirements (later section), it is anticipated that pre-mounting low-friction rack slides will be needed to support the Brazos chassis.
 - FRU module installation/removal
Hand forces to remove/install or otherwise manipulate FRU modules shall not exceed the values shown in the following table.

Hand Operation		Max force (lbf)
Finger press (1 index finger)	Frequent ($\geq 2/\text{min}$)	3.4
	Infrequent ($< 2/\text{min}$)	8.6
Finger press (2 fingers, same hand)	Frequent ($\geq 2/\text{min}$)	5
	Infrequent ($< 2/\text{min}$)	12.5
Finger press (2 fingers, different hand)	Frequent ($\geq 2/\text{min}$)	11
	Infrequent ($< 2/\text{min}$)	27.5
Finger pull (1 finger)	Frequent ($\geq 2/\text{min}$)	3.9
	Infrequent ($< 2/\text{min}$)	9.6
Finger pull (2 fingers, same hand)	Frequent ($\geq 2/\text{min}$)	8.4
	Infrequent ($< 2/\text{min}$)	20.9
Thumb press (1 thumb)	Frequent ($\geq 2/\text{min}$)	5.3
	Infrequent ($< 2/\text{min}$)	13.3
Thumb press (2 thumb)	Frequent ($\geq 2/\text{min}$)	10
	Infrequent ($< 2/\text{min}$)	25
Pinch grip (chuck grip, with wrist deviation)	Frequent ($\geq 2/\text{min}$)	2
	Infrequent ($< 2/\text{min}$)	4
Pinch grip (chuck grip, without wrist deviation)	Frequent ($\geq 2/\text{min}$)	3.2
	Infrequent ($< 2/\text{min}$)	7.9
Pinch grip (key grip, with wrist deviation)	Frequent ($\geq 2/\text{min}$)	2
	Infrequent ($< 2/\text{min}$)	4.8
Pinch grip (key grip, without wrist deviation)	Frequent ($\geq 2/\text{min}$)	3.9
	Infrequent ($< 2/\text{min}$)	9.7
Insertion/Removal w/ 1-handed grip	Frequent ($\geq 2/\text{min}$)	6.7
	Infrequent ($< 2/\text{min}$)	16.9
Chuck grip: thumb opposing pads of index, middle finger		
Key grip: thumb opposing side of index finger		

Table: 12.1: Maximum force limits for hand operations

- LED Indicators - The recommended LED implementation is described below.
 - The front face of the Chassis will have two LEDs to indicate unit status. The first LED will be blue, and will be on to indicate that the unit is powered on and running. The 2nd LED will be amber, and normally off. When there is an error or attention is needed for the unit, the amber LED will be lit.

- The hot swappable FRU modules will also each have 2 LEDs or a bi-color LED, either within the device or adjacent to it. The first LED will be blue, and will be on to indicate that the FRU module is powered on and running. The 2nd LED will be amber and normally off. When there is an error or attention is needed for the unit, the amber LED will be lit. In the case of a bi-color LED, only one color should ever be on at a time - if there is a reason the yellow LED is lit, then the blue LED shall be off.
- When there is an error and the amber LED is illuminated the error code(s) and description(s) shall be indicated on the HMI and also reported externally by the controller through the Modbus connection
- Labeling for device identification
 - The front and rear faces of the chassis shall have a Unit ID label, consisting of the Part number (PN) and Serial Number (SN) of the assembly. The PN and SN content is to be in human readable and 1D barcode formats on separate lines for each value.
 - Each FRU module shall include a PN and SN Label which has both human readable and scannable barcode formats. 1D barcodes are preferred, but may be 2D if space is limited. Placement of the PN and SN label on the external face of the FRU is preferred, but may be internal if space is limited.
 - All Serial Numbers shall be unique across all Part Numbers, meaning no repeats of SN value (before the date or sequence portion of the SN) on any other FRU even though PNs are different.
 - Format of SN content (e.g. prefix, date code, # of digits for serialization) to be approved by customer
 - Each chassis shall include a MAC address label. The label shall list the MAC address in human readable format and also in a scannable 1D barcode format. If the MAC address is tied to a FRU (changes if the FRU is swapped), it shall be placed on the exterior face of the FRU module. If the MAC address is tied to the chassis (does not change except only if the whole chassis is swapped), then the MAC address label shall be placed on both the front and rear faces of the chassis.
 - All connectors/ports (electrical or fluid) accessible by the user/operator shall be labeled according to their function.
 - For FRU types which have more than 1 instance installed in the chassis assembly, the chassis shall include labeling to indicate the location of each FRU item number. Physical label naming and numbering to match how the system software and the HMI name the items.
- Additional FRU module design features
 - Hot-swappable FRU modules are to have tool-free retaining and release features and touch/handling locations identified if they are not an obvious handle or latch.
 - Handling features on FRU modules, including features to retain/release the FRU from the chassis are to be a consistent identifying color throughout the product.

- Color for 1st Supplier is to be Blue
- Color for 2nd Supplier is to be Orange
- Exact color specification (e.g. Pantone color match system) to be discussed with supplier
- Comparing FRU modules between the 1st supplier and the 2nd supplier, they shall include physical differences (i.e. keying) to prevent each type of FRU module from one vendor from inserting into the corresponding opening in the other supplier's chassis.
 - Differences are to be obvious and prevent the appearance of a proper insertion even though it is not mated
 - Keying features are not to cause damage to any connections if one supplier's FRU is attempted to insert into the other supplier's chassis.
- FRU modules shall be blind mating, with guiding or aligning features.
- FRU modules shall be able to disengage 1 inch or half its insertion length (whichever is smaller) while being supported by guide features to prevent falling out of the chassis.
- All FRUs shall complete functional testing before shipment to the customer.
- All screws which must be loosened or removed during field service of a unit (to swap a full chassis or a serviceable component or to gain access to a serviceable component) and which require a tool to loosen said screw, must accept a Phillips #2 driver as the tool to loosen & re-tighten the screw.

13 Leak detection & mitigation

- The Brazos control system shall include fluid leak detection cable for any liquid leaks which occur within the aCDU chassis volume
- The Brazos control system shall include fluid leak detection cable for leaks which occur outside of the aCDU chassis. This cable shall be connected to the Brazos controller but routed externally and placed on the floor in front of the IT rack in which the Brazos chassis resides. The length of the external cable shall extend 17 feet (+6/-0 inches) so that it may span the width of multiple racks either along the floor or above the racks in above-rack drip trays for above-rack manifold connections.
 - The external cable shall plug into a connector that is accessible at or near front of the Brazos chassis for serviceability/swappability.
- Any minor liquid leaks occurring within the chassis volume shall be contained within the chassis base and routed to the front of the aCDU chassis and be evacuated/drained from the front of the aCDU chassis in a manner that can be controlled and routed with tubing. (In the context of this bullet point, "minor" means whatever can be contained/controlled & routed out the front drain points.)
 - The objective of the evacuation scheme is to evacuate the coolant to reduce coolant accumulation inside of the chassis

- For leaks larger than what can be managed by the features for the above consideration, and for multiple Brazos aCDU chassis stacked vertically adjacent within one rack, leaks within one Brazos chassis shall have no impact on the performance or safety of any other Brazos chassis.
 - The context here is regarding direct effects of the fluid which has escaped the normal operation flow path. Effects of lack of fluid within the system to be addressed by sensors & warnings/alarms in other system requirements.
- Any leak occurring within a Brazos chassis shall not create any other hazards (e.g. electrical or fire) within the chassis.
- Brazos units shall not be daisy chained, i.e. each Brazos unit shall have individual and independent leak detection.
- Need two leak detection cable kits (one for floor and one for above the rack) to be sold separately (vs two extra kits per Brazos unit)

14 Acoustics

- Acoustic requirement for *front and rear* of the Brazos rack with 3 Brazos chassis
 - Applicable scenarios:
 - Device start up condition for all devices within the rack
 - Fans in all subcomponents are functioning at nominal/TDP condition with all fans working.
 - Fans in one of the subcomponents with highest acoustic noise are in fan fail safe mode. All other remaining subcomponents are functioning at nominal/TDP condition with all fans working
 - Locations of measurement (2 on front and 2 at rear of rack):
 - 100cm and 158cm up from ground
 - 38 cm away from the rack front and rear surface
 - Max limit ≤95dBA
 - Preferred limit ≤85dBA

15 Safety

- Certification
 - UL/cUL
 - CB
 - CE Mark
 - Scope
 - UL Recognition of the closed loop liquid cooling system
- Standards
 - 62368-1
- Miscellaneous Items

- [Slide rail design](#) shall comply with mounting means for slide-rail mounted equipment (SRME) requirements in section 8.11 of UL/IEC 62368-1.
 - Grounding per UL 60335-1, Section 27.5DV.1 (D1 National Difference)
 - The enclosure must be in compliance with UL/IEC 60335-2-40 and 62368-1 prescriptive requirements.
 - Pressure relief valve - A safety PRV shall be in the rack water supply manifold or piping with no valve before the connector intended for connection to the host rack's rack manifold.
 - One of the two options below:
 - UL certified component rated for the application and suitability approved by UL, or
 - ASME test report for the pressure relief valve showing compliance with the Boiler and Pressure Vessel Code, Section VII, bear the UV symbol and be stamped with the set pressure, capacity, and pipe size; and "Start-To-Discharge" tested by UL per UL 471 - Commercial Refrigerators and Freezers, Section 70; excerpt inserted below.
- 70 Start-To-Discharge Test**
- 70.1 A pressure-relief device used in the carbonation system shall relieve at a pressure not exceeding its rated start-to-discharge pressure.
- 70.2 Three samples of the device are to be tested. Each sample is to be connected to a gas source, such as air, carbon dioxide, or nitrogen, but oxygen or any flammable gas is not to be used. The sample is to be immersed in water, and the pressure is to be gradually increased until the device starts to discharge as evidenced by the occurrence of bubbles in the water. The highest value obtained in tests of the three samples is to be used to determine compliance with 70.1.
- Minimum V0 flammability rating for all plastic material; hoses shall have both V0 and VW-1 flammability ratings
 - Minimum VW-1 flammability rating for all cable and wiring
 - Minimum CL2P flammability rating for water sense cable

- Supplier is responsible for all aspects of safety design, utilizing high-level design specifications and inputs provided by the customer.
- Supplier to review schematics, layout and mechanical enclosure designs to assess safety risks, request design changes as needed and monitor design changes that could impact safety performance. Supplier will provide written documentation for the design review process.
- Supplier is responsible for performing all safety-validation tests and formal certification tests as per Test Plan approved by the customer and sharing written test results with the customer.
- In addition to 60335, subassemblies employed within the system that do not fall under the scope of the standard shall be qualified, tested and certified to the appropriate standard as applicable.
- Supplier to obtain UL/C or an equivalent NRTL/C with follow-up service, and IECCE CB Reports to include all national deviations as specified in the most current CB Bulletin.

16 EMC

The fully integrated Brazos Coolant System shall be designed to comply with requirements for Class A devices when tested according to CISPR 32 and CISPR 35 standards, and applicable national regulations (i.e. FCC CFR 47, part 15 in the USA, ICES-003 in Canada, EN 55032 and EN 55035 in Europe, etc.) across the full range of supported operations and configurations (i.e. idle, normal, minimum/maximum workloads, etc.) in addition to the following requirements.

Test	Test Method	Requirement
RE/CE	CISPR 32; FCC Part 15	-6 dB margin (Class A)
ESD	EN 61000-4-2	Contact: +/-6 kV & Air: +/- 8 kV Criteria B
RI	EN 61000-4-3	10V/m Criteria A
EFT	EN 61000-4-4	+/- 2kV @ 5kHz & 100kHz Criteria B
Surge	EN 61000-4-5	±1 kV Criteria B
CI	EN 61000-4-6	3 Vrms Criteria A

Table 16.1: EMC test requirements

17 Regulatory compliance

- The Products shall be designed for compliance to allow worldwide deployment
- Supplier to obtain applicable certifications for the product to enable worldwide deployment and provide a certification plan with complete schedule, including test location and applicable standards.
- All evaluations must be as comprehensive as possible. Only requirements that absolutely rely on or are affected by the system may be left to the system level evaluation [i.e. minimize Conditions of Acceptability].
- Any exceptions and all Conditions of Acceptability must be confirmed and agreed upon by the customer Product Compliance Engineering.
- Ensure that the Products comply with all applicable legislation, regulations, codes of practice, guidance and other measures on substances and materials considered hazardous to health and/or the environment.

- Ensuring the complete compliance of the Products in the environment it is intended to function.
- Maintaining the certification of the Products which includes but is not limited to re-certification and/or any re-testing that may become required due to changes or revisions in the standards or regulatory requirements.
- All homogenous materials in the product must comply with Restricted Substances Specifications as required by the customer.
- Product labeling should comply with following requirements and get compliance approvals (see Marking & Labeling guideline)

Essential requirements

- Company name, trademark, brandname, or other identification
- Product Type
- Certified Model Number/Name
- Electrical ratings
- Country of Origin
- Certification marks
- In some cases: warning/cautions markings may be applicable

Materials

- UL RECOGNIZED PER UL 969 MARKING AND LABELING SYSTEMS (PGDQ2) OR CSA CERTIFIED PER CAN/CSA22.2 NO. 0.15

Label placement

- Visible and legible
- Not subject to physical damage during handling/installation
- Affix to a non-removable part
- Label shall be affixed on the device and on the package
- Label size can adjust to accommodate compliance markings and/or fit application location
- Component level labels should be placed on a surface that will be hidden after installation. (avoid confusion with system level labeling)

18 Control and monitoring

18.1 Physical Layer Hardware Connectivity

- **Ethernet Uplink Port:** Standard RJ45 connector located on the front face of the controller labeled "ENET". Physical layer speed is limited to 10/100BASE-T Auto-negotiation.
- **Local HMI Interface:** Communication to a front-panel HMI is over a dedicated UART serial connection routed from the MCU.

- **USB Service Console Port:** Front-facing USB port must allow the port to be completely disabled to comply with physical data center security protocols.

18.2 Networking & Messaging Protocols

- **Dual IPv4/IPv6 Stack:** The controller must natively support concurrent IPv4 and IPv6 on the "ENET" port.
- **DHCP & Network Telemetry:** DHCP configuration requests must transmit DHCP Option 60 (Vendor Class Identifier) with the explicit string value "Brazos v1". Telemetry and register reading are mapped via Modbus over TCP.
- **Redfish Management Standard:** System configuration, asset variables (serial numbers, firmware versions), and real-time sensor metrics are exposed via the Redfish RESTful API to support standardized out-of-band management.

18.3 Firmware Upgrade & Safety Architecture

- **Dual Partition Image Layout:** Storage must utilize an "a/b" dual-image partition scheme in flash memory to protect against corrupted upgrades and enable atomic rollbacks.
- **Upgrade Verification & Integrity:** All firmware update binaries are processed through a strict HTTP POST API. The controller must execute a safety and integrity check on the uploaded binary using a 16-bit CRC or stronger checksum, ensuring a failure-to-detect rate of random corruption of <0.001% before execution.

18.4 Dry-Run Prevention Interlock

- **Safety Interlock:** Pumps are strictly prohibited from turning on upon initial live insertion of the power board into the rack busbar.
- **Verification Step:** The controller must verify that the suction pressure / liquid level sensor confirms the presence of liquid before enabling the pump variable frequency drives (VFDs) to prevent dry-running damage.

19 Controls operating modes

- **Automatic controls**
 - Pump auto controls
 - **DEFAULT:** Fixed pressure drop control → control pump speed to maintain fixed pressure differential between liquid supply pressure sensor and liquid return sensor
 - Additional selectable pump controls
 - Fixed flow
 - Fixed supply temperature
 - Fixed return temperature

- Fixed speed
 - The pumps shall be controlled as a function of the average pressure drop calculated by the pair of redundant sensors while both pairs of sensors are reporting within the sensor accuracy relative to the average of the sensor readings. If either of the individual pair of sensor readings is outside of the expected sensor accuracy then the pumps shall be controlled by the pair of sensors reporting the lower pressure drop until both pairs of sensors are swapped.
- Fan auto controls
 - **DEFAULT:** Approach temperature control → control fan speed to maintain fixed approach temperature as defined below based on inlet/supply air temperature and outlet/supply liquid temperature measurements
 - $\Delta T_{\text{approach}}$ is defined as:

$$\Delta T_{\text{approach}} = T_{\text{liquid supply, cold}} - T_{\text{air supply, cold}}$$
 - Additional selectable fan controls
 - Fixed speed
 - Fixed exhaust temperature
 - The fans shall be controlled as a function of the average approach temperature calculated by the redundant sensors while the sensors are reporting within the sensor accuracy relative to the average of the sensor readings. If either of the sensor readings is outside of the expected sensor accuracy then the fans shall be controlled by the pair of sensors reporting the greater approach temperature until both pairs of sensors are swapped.
- Max liquid temperature control
 - This control mode will limit the hot liquid temperature returning to the aCDU (inlet to the aCDU, i.e. outlet from IT equipment) to a temperature setpoint that can be changed. In our application the default value should be 55 °C, but the temperature setpoint should be configurable at the HMI and remotely as needed.
 - This control mode should be triggered only when the liquid temperature reaches or exceeds the specified temperature threshold.
 - This control mode should supersede other automatic control modes.
 - DEFAULT is ON, but shall be switchable to OFF at the HMI (locally) and remotely as needed.
- Max air temperature control
 - This control mode will limit the hot air temperature leaving the aCDU to a temperature setpoint that can be changed. In our application the default value should be 50 °C, but the temperature setpoint should be configurable at the HMI and remotely as needed.

- This control mode should be triggered only when the air temperature reaches or exceeds the specified temperature threshold.
- This control mode should supersede other automatic control modes.
- DEFAULT is ON, but shall be switchable to OFF at the HMI (locally) and remotely as needed.
- **T2 automatic controls**
 - There may (eventually) be a 2nd tier (T2) controller job run on the facility monitoring infrastructure that adjusts the local PLC controller setpoints in real time. The objective is to optimize efficiency by coordinating operation across multiple Brazos devices.
 - The T2 controls provide min/max bounds on the aforementioned section "Automatic controls" and otherwise behaves as in described in that section.
 - The variables are prefixed with "t2-" and are:
 - t2-timeout-in-sec
 - t2-pump-speed-min
 - t2-pump-speed-max
 - t2-fan-speed-min
 - t2-fan-speed-max
 - The controller will guarantee that all pump and fan speeds will remain within the specified range while the value in register **t2-timeout-in-sec** remains positive.
 - If the current pump or fan speed is outside the min/max boundary, the controller will slew the pump or fan speed at a safe rate until it is within range. The controller is to make the minimum change to fulfill this requirement.
 - The type for the registers may be signed or unsigned. If a signed type is used, negative values shall be treated the same as 0.
 - T2 Enable/Disable (T2 Timeout Behavior): To enter T2 control, the T2 controller is required to write a non-zero, positive value into the **t2-timeout-in-sec** variable. Once a non-zero, positive value is written, the controller will enter T2 control. The PLC then decrements this value once per second. When it reaches zero, the PLC will exit T2 control.
 - Transfer between local T1 control shall be bumpless.
 - The objective of this section is to smooth the transfer in and out of T2 operation. This section will use the term "T2 variables" to refer to all T2 setpoint variables **except** the timeout variable.
 - When the PLC is not in T2 control, it will write the equivalent pump speed setpoints to the corresponding T2 setpoints.
 - When the PLC is in T2 control, it will observe the T2 setpoint variables.
 - When the T2 system starts T2 control, it will start control from the current value in the T2 variables, slewing them to the desired value.
 - When PLC exits T2, it will start control from the current value in the T2 variables, slewing them to the desired value.

Local Control Normal Operation

Brazos pump control operates in one of the following modes:

- **Normal (auto)** - pump speeds controlled by dP setpoint by default.
- **T2 (supervisory)** - pump speeds controlled as in Normal (auto), but with min/max bounds managed by a supervisory control system. See the above section "T2 automatic controls" for details.
- **Manual** - overrides failsafe conditions, performed through HMI or remotely
- **PLC Failsafe** - pumps controlled to failsafe speed by controller in the event of sensor failures. Default failsafe speed shall be 100%
- **Pump Failsafe** - pump firmware shall increase speed to 100% if communication is lost with the controller or if either pump fails. Default failsafe speed shall be 100%.
- **Operator Mode** - enabled on the operator interface, normally only used during verification and test

Fan control will operate in one of the following modes:

- **Normal (auto)** - normally controlled by approach temperature setpoint by default
- **T2 (supervisory)** - fan speeds controlled as in Normal (auto), but with min/max bounds managed by a supervisory control system. See the above section "T2 automatic controls" for details.
- **Manual** - overrides failsafe conditions, performed through HMI or remotely.
- **PLC Failsafe** - fans controlled to failsafe speed by controller in the event of sensor failures. Default failsafe speed shall be 100%
- **Fan Failsafe** - fan firmware shall increase speed to 100% if communication is lost with the controller or if one fan fails. Default failsafe speed shall be 100%.
- **Operator Mode** - enabled on the operator interface, normally only used during verification and test

Startup

- The pumps shall not startup without liquid, i.e. pumps must be able to detect the presence of liquid before startup.
- The default pump and fans control at startup shall be manual mode.
 - This shall be configurable at the HMI or remotely.
- The default pump speed at startup shall be 25%. This value shall be configurable at the HMI or remotely
- The default fan speed at startup shall be 25%. This value shall be configurable at the HMI or remotely
- The controller shall perform a system diagnostic check at startup.

Reboot

- At startup/reboot after a power failure/interruption or software update the controller shall maintain the last state (e.g. manual, auto controls, etc.) in which the controller was in before the reboot.

Controls of multiple Brazos in a single rack

- Requirement
 - If a Brazos unit fails, the remaining Brazos units need to meet thermal-hydraulic demand
 - The Brazos unit should provide similar thermal-hydraulic performance (similar pump & fan speeds)
 - Brazos units must have provisions for Tier 2 control.
 - Automatic/remote vs local
 - Heartbeat
 - Brazos must have setpoints for the minimum fan speed and minimum pump speed.
 - Each Brazos units should be capable of running in manual mode (hold pump / fan speeds via HMI)

20 Internet Protocol version

The product shall support IPv4 and IPv6.

21 Software & firmware

There are no fixed requirements for the firmware. Functionality is defined by the thermal cooling requirements. Beyond basic functionality

- Detailed failsafe condition handling.
- Remote firmware update capability.
- Component supply for the life of the product (Target 10-15 years).
- Set DHCP Option 60 to the string "Brazos v1".

Software requirements are defined by the collector/controller service being used.

The firmware shall:

- Support an "a/b" dual-image scheme.
- Publish telemetry over Modbus according to the standard telemetry signals and variables defined in Section 21.4.
- Second-source suppliers shall adhere to the standardized Modbus telemetry variables defined in Section 21.4.
- Support remote firmware updates. Shall implement the interface documented at below.

21.1 Remote Update Process

This is a high level description of the firmware update process per se. Details of the specific interfaces are below.

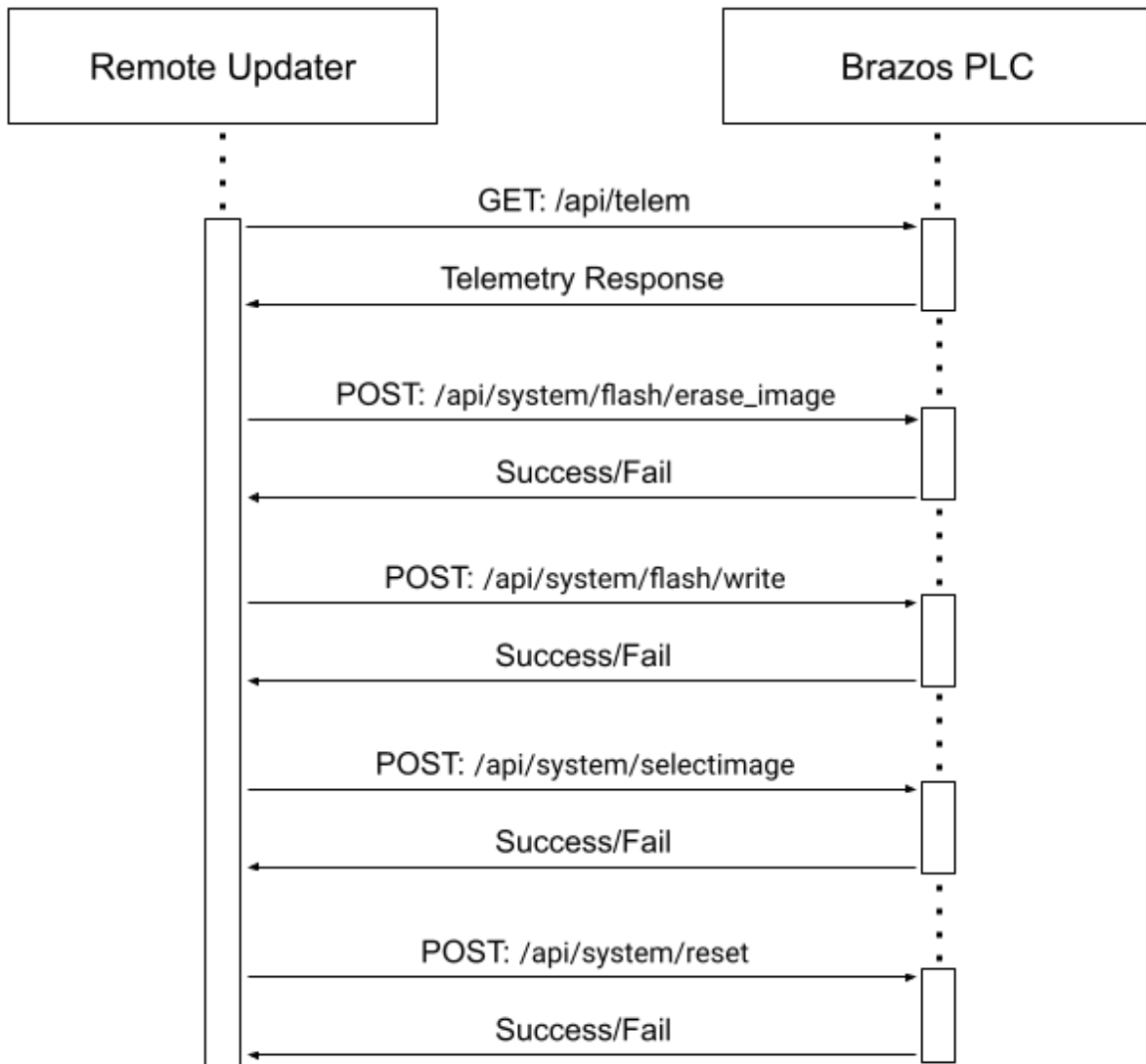


Figure 21.1: Schematic diagram of the firmware update process.

The update process starts with getting the currently running image via an HTTP GET at "/api/telem". This will return telemetry, which will include a metric named "/flash/running-image", the value of which is either "a" or "b", depending on which image is running. This value is used

for selecting the correct image to upload and for determining what value should be written to `"/api/system/selectimage"` (see below).

The updater tool then will request erasure of the memory location of the non-running image by making an HTTP POST call to `"/api/system/flash/erase_image"`.

The non-running image is updated by making an HTTP POST call to `"/api/system/flash/write"` with the POST body containing the binary image of the firmware intended for that partition..

Next, the image selector is updated by making an HTTP POST call to `"/api/system/selectimage"` with the POST body containing the image for the device to boot into, "1" for side "a" and "2" for side "b".

Lastly, the device is to be remotely rebooted by making an HTTP POST call to `"/api/system/reset"`.

21.2 Remote Update Interface

The PLC shall implement an HTTP server listening on port 3913.

The following paths will be defined:

- `/api/system/flash/erase_image`
- `/api/system/flash/write`
- `/api/system/reset`
- `/api/system/selectimage`
- `/api/telem`

Undefined paths shall return an error 404 with the error message, "The requested path does not exist."

Each interface/path is independent of the others, and should be able to be called independently.

Requests must not be authenticated.

The HTTP server shall be able to accept the maximum firmware size in a single POST request.

- This may be implemented by setting the maximum supported size for a single POST request such that it exceeds the maximum amount of memory available for firmware images.
- The intent is to avoid having to upload a firmware image using multiple POST requests.

Firmware images (an "A" or "B" image) should not exceed 2 GiB, the protocol buffer size limit for 'bytes' fields. In the event this is not feasible, DCEH Cooling should be advised promptly.

/api/system/flash/erase_image: Erase Partition

This server shall wait for POST requests at the path `"/api/system/flash/write"`, which will allow the caller to erase a partition (reset it to 0s).

The payload of the POST request is a [wire format protocol buffer](#) message:

```
None
message FlashEraseCommand {
  uint32 address = 1;
  uint32 length = 2;
}
```

`address` shall contain an address specifying the first byte to be erased.

`length` shall contain the number of bytes to overwrite.

The server shall wait until completion of the erasure before returning.

This interface may not perform any action if and only if the firmware write implementation (at path `"/api/system/flash/write"`) performs a similar step or otherwise provides a guarantee that executable code or data does not remain past the end of a new, smaller, image.

On success, the device should return with HTTP status 200 and a message reading "Ok".

On failure, the device should return with HTTP status 500 and a message that explains the nature of the failure.

/api/system/flash/write: Firmware Writes

This server shall wait for POST requests at the path `"/api/system/flash/write"`, which will allow the caller to write a new firmware image to the non-running partition.

The server shall support streaming POST requests.

The payload of the POST request is a [wire format protocol buffer](#) message:

```
None
message FlashCommand {
    uint32 address = 1;
    bytes data = 2;
}
```

address shall contain an address specifying where the bytes should be flashed. This may be ignored (for the purposes of firmware writes per se) if another scheme is used.

data shall contain an array of bytes to write to the specified address. This is the firmware image to be installed. The byte order shall be exactly that which is provided to the customer by the firmware authors.

Upon successful completion of safety checks, the PLC is expected to flash its firmware with the bytes received and reboot to start using the new firmware version.

The server shall wait for the write to complete before returning a response.

On success, the device should return with HTTP status 200 and a message reading "Ok".

On failure, the device should return with HTTP status 500 and a message that explains the nature of the failure.

Safety Checks

The following safety checks shall be performed on the uploaded data:

- The uploaded firmware can fit in the available space.
- Verify the uploaded image's checksum before updating.
 - Shall be implemented as a 16-bit CRC or other method that provides a similar or better guarantee against failure to detect random corruption.
 - If a different method is used, it must have a probability to detect a random change that is no worse than 99.999% (approximately that of 16-bit CRC's probability of failure to detect a random change).
 - Stronger guarantees are preferred.
 - Details for the checksum implementation shall be documented and shared with the customer, so that we may successfully publish our own images. These details shall include, but not be limited to:
 - Checksum algorithm.
 - What parts of the firmware image are checksummed.

- The location of the checksum in the image.
- Verify the uploaded image is the correct one for the partition ('a' or 'b' side) it will be written to.
- If the 'address' field is used, that the given address will result in a write that:
 - Starts in the correct location in address space.
 - Does not overrun the available space.

Should safety checks fail, the firmware should reject the firmware update with an error message describing the check that failed.

It is acceptable for this interface to also automatically perform the functionality provided by `"/api/system/selectimage"`.

`/api/system/selectimage`: Change bootable image

This server shall wait for POST requests at the path `"/api/system/selectimage"`, which will allow the caller to write a new firmware image to the non-running partition.

The payload of the POST request is a [wire format protocol buffer](#) message:

```
None
message message ImageSelect {
  enum ImageSection {
    A = 1;
    B = 2;
  }

  ImageSection image = 1;
}
```

It is acceptable for this interface to not do anything (i.e., not be implemented and always return success) if and only if the firmware update path `"/api/system/flash/write"` implements this functionality.

On success, the device should return with HTTP status 200 and a message reading "Ok".

On failure, the device should return with HTTP status 500 and a message that explains the nature of the failure.

`/api/system/reset`: Remote reboot

The server shall wait for POST requests at this path, which will result in the device rebooting into the new, selected image. The POST body should be disregarded.

On success, the device should return with HTTP status 200 and a message reading "Ok" prior to rebooting.

On failure, the device should return with HTTP status 500 and a message that explains the nature of the failure.

/api/telem: Get telemetry

The server shall wait for GET requests at this path, which will return device telemetry. The request body currently has no fields.

The response is a [wire format protocol buffer](#) message:

```
None
// Basic type for holding one piece of telemetry from a device.
message StreamzValue {
  // Streamz metric name; e.g., "/flash/running-image".
  string streamz_name = 1;

  // Device name.
  // Set to "brazos_${device_mac}"; e.g., "brazos_12:34:56:78:9A:BC".
  string device_name = 2;

  // Doc string for Streamz. Leave unset (i.e., omit), or give the empty string.
  string doc = 3;

  // Units for Streamz. Set to the empty string.
  string units = 4;

  // Only one of the following *_value types should be populated.
  string string_value = 5;
  int64 int_value = 6;
  float float_value = 7;
}

// Response used for standard telemetry request (GET request to /api/telem).
message RxResponse {
  repeated StreamzValue streamz = 1;
```

```
}
```

The following name/value pairs shall be defined:

streamz_name	value_field	value
/flash/running-image	string_value	'a' or 'b'; whichever image is currently running.
/flash/select-image	string_value	'a' or 'b'; whichever image is currently the default/primary image.
/flash/image-a-version	string_value	Version string for the image that's written to this side.
/flash/image-b-version	string_value	Version string for the image that's written to this side.

Table 21.1: streamz name and value pairs

On success, the device should return with HTTP status 200 and the body of the response should be the specified protocol buffer data.

On failure, the device should return with HTTP status 500 and a message that explains the nature of the failure.

21.3 Component Firmware Updates

We propose including component firmware into the controller firmware image, and using that as a mechanism for getting updates to these parts.

21.4 Telemetry signals/variables for controls & monitoring

Controller	Read (R) or Read/Write (R/W)
Controller FW version	R
Controller uptime (Hours)	R
Pump PID enable	R/W
Fan PID enable	R/W

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PID controls manual vs auto	R/W
Pump FW version	R
Pump serial number	R
Fan serial number	R
Pump PID proportional	R/W
Pump PID integral	R/W
Pump PID differential	R/W
Pump PID deadband	R/W
Pump PID sample frequency	R/W
Fan PID proportional	R/W
Fan PID integral	R/W
Fan PID differential	R/W
Fan PID deadband	R/W
Fan PID sample frequency	R/W
Approach temperature PID setpoint	R/W
Differential pressure PID setpoint	R/W
Fixed flow PID setpoint	R/W
Pump run hours (Run Hours = Powered Hours – Standby Time)	R
Pump powered hours	R
Leak detection controller FW version	R
Pump speed failsafe setpoint	R/W
Fan speed failsafe setpoint	R/W
Pump speed min setpoint	R/W
Pump speed max setpoint	R/W
Fan speed min setpoint	R/W
Fan speed max setpoint	R/W
Flow min setpoint	R/W
Flow max setpoint	R/W
Pressure min setpoint	R/W
Pressure max setpoint	R/W
Differential pressure min setpoint	R/W
Differential pressure max setpoint	R/W

Temperature min setpoint	R/W
Temperature max setpoint	R/W
Temperature	
Inlet air	R
Outlet air	R
Liquid supply	R
Liquid return	R
Controller	R
Pump drive	R
Pressure	
Liquid supply	R
Liquid return	R
Filter supply	R
Filter return	R
Power	
aCDU power in	R
aCDU power out	R
Pump power	R
Fan power	R
Voltage	
Internal aCDU power rail voltages	R
Pump voltage	R
Fan voltage	R
Current	
aCDU current in	R
aCDU current out	R
Pump current	R
Fan current	R
Speed	
Pump speed (actual)	R
Pump speed (commanded)	R/W
Pump speed offset from command	R/W
Fan speed (actual)	R

Fan speed (commanded)	R/W
Fan speed offset from command	R/W
Tier-2	
T2 timeout (in sec)	R/W
T2 pump speed min	R/W
T2 pump speed max	R/W
T2 fan speed min	R/W
T2 fan speed max	R/W
Fluid level	
Reservoir (if present)	R
Expansion tank (if present)	R
Leak	
Leak distance floor	R
Leak distance aCDU	R
Leak count floor	R
Leak count aCDU	R
Leak resistance floor	R
Leak resistance aCDU	R
Flow	
Liquid flow rate	R
Faults	
aCDU status	R
Leak sensor status (normal vs fault)	R
Temperature sensors status (normal vs fault)	R
Pressure sensors status (normal vs fault)	R
Liquid flow sensors status (normal vs fault)	R
Reservoir fluid level sensors status (normal vs fault)	R
Pumps status (normal vs fault)	R
Fans status (normal vs fault)	R
Controller board status (normal vs fault)	R
Power board status (normal vs fault)	R
Pump number of stalls	R

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Pump number of overtemperature	R
Pressure too high	R
Pressure too low	R
Pump speed too high	R
Pump speed too low	R
Fan speed too high	R
Fan speed too low	R
Liquid flow too high	R
Liquid flow too low	R
Pump drive temperature too high	R
Pump drive temperature too low	R
Pump drive power too high	R
Pump drive power too low	R
Pump drive current too high	R
Pump drive current too low	R
Pump drive voltage too high	R
Pump drive voltage too low	R
Pump number of overcurrents	R
Pump drive number of over temperature	R
Pump drive number of stalls	R
Pump drive number of overcurrents	R
Pump drive run hours	R
Pump drive powered hours	R
Pump drive number of PFC faults	R
Pump number of power supply faults	R
Pump number of address faults	R
aCDU power too high	R
aCDU power too low	R
aCDU current too high	R
aCDU current too low	R
aCDU voltage too high	R
aCDU voltage too low	R
Fluid level too high	R

Fluid level too low	R
Pump speed limited due to suction pressure too low	R
Pump speed limit count (# of times the pump speed was limited)	R

Table 21.2: Telemetry signals/variables for controls & monitoring

22 Manufacturing

- The supplier shall implement a fully electronic manufacturing execution system (MES).
- The supplier shall provide a DFX document package including but not limited to Line Matrix (Factory Layout, Process Flow, Line Balancing), Process Assembly/3D-SOP, DFM, Tolerance Analysis (TA), PFMEA, Process Control Document (PCD).
- The supplier shall provide a Change Control Table (CCT) for process changes.
- The supplier shall provide MSA / Gage R&R analysis.
- The supplier shall provide an 8D report for Failure Analysis.

23 Shipment requirements

- The equipment shall be purged of liquid, dried and charged with nitrogen gas at a pressure of 10 psi before packaging and shipment.
- The supplier shall provide Packaging Design & Validation.
 - The supplier shall apply best practices to design packaging for “ergonomically friendly” loading and unloading of equipment into and out of packaging, respectively
- All product FRUs shall have an individual part packaging solution for shipment.

24 Second source components

- All components shall be second sourced. If second sourcing is not possible the vendor shall notify the customer and propose an exception for consideration by the customer.
- First and second source components shall be able to be “mixed and matched” within the same Brazos assembly, e.g. pump supplier A’s pump shall be able to operate with pump supplier B’s pump.
- The Brazos rack shall contain 3 Brazos aCDU units from the same vendor, i.e. the Brazos rack shall not have Brazos aCDUs from multiple vendors.

25 Documentation and tools

- Vendor shall provide detailed documentation, user manuals, Standard Operating Procedures (SOPs) for
 - Installation

- Commissioning (filling, draining, pressurization, drawing coolant samples)
- Troubleshooting
- Service
- Service frequency
- FRU replacement
- Tool for priming the pump cassette

26 Validation

26.1 Thermal-hydraulic testing

Notes:

- Vendor to document and share details of set up and procedures for all the tests.
- Following qual plan is applicable to EVT/DVT/PVT
- (Few tests can be exempted during DVT and PVT depending on changes made to the product.)
- Vendor to share test reports and detailed tests data

Brazos thermal performance at different power levels.

- Approach temperature/acoustics/aCDU power Vs Heat load for 10 kW to 30 kW in steps of 2kW with
 - Pump and fan on Auto control
 - 30 °C entering air temperature (EAT)
 - Exhaust back pressure of 0,0.01, 0.05 and 0.125 in.-H₂O
 - Airflow (based on air temperature rise): 10 °C, 15 °C, 20 °C

Brazos hydraulic and acoustic performance

- Pump flow, power, efficiency vs speed with 10% speed steps
- Fan flow, power, efficiency vs speed with 10% speed steps
- Liquid side flow rate vs pump speed with 10% speed steps
 - with and without redundancy
- Airflow rate vs fan speed with 10% speed steps
 - with and without redundancy
- aCDU level PQ (like fan curve) for liquid with 10% speed steps
- aCDU level PQ (like fan curve) for air with 10% speed steps
- Acoustics tests:
 - Fan speed sweep from min to Max in steps of 10%
 - Each fan speed with 2-3 pump speeds (to account for pump acoustics)

Controls validation

- Validate aCDU response time for following step change in heat load
 - 10 kW → 20 kW

- 20 kW → 30 kW
- Validate fan/pump/aCDU response for:
 - Fan failure
 - Pump failure
 - Controls failure
 - Telemetry loss
 - Leak detection
- Monitoring validation
 - Report entire telemetry from aCDU for above tests.
 - Validate accuracy of values reported through monitoring for flow, DP, temperature, fan RPM, Pump RPM.
 - Validate reporting of fail safe events
 - Fan failure
 - Pump failure
 - Controls failure
 - Telemetry loss
 - Leak detection

26.2 Acoustics

Measurement Method:

- Measure A-weighted Sound Pressure Level at a distance of 38 cm from the chassis faces with all fans operating at 100% PWM.
- Applicable to each face: front, rear, left and right.
- The device should be on a 75cm tall table top with no overhang.
- The microphones should be centered with the corresponding faces horizontally and vertically (at a distance of 38 cm).
- Sweep the fan speed from min to max in step of 10%.
- The ambient SPL should be at least 7 dBA lower than the chassis SPL at the lowest fan speed. The chassis should be turned off completely to measure the true ambient SPL.
- Use Class 1 sound pressure level meter and acoustic spectral analyzer per IEC 61672.

Acoustic Report

The report must contain the following information:

- UUT Description
 - Make and Model
 - Fan Model Numbers
 - Qty and Location of Fans
 - Any other relevant information about UUT
 - Links to product data sheets
 - Pictures of the UUT
- Test Location

- Date of Test
 - Lab address if it can be shared
 - Pictures
- Test Setup
 - Type of chamber or room
 - Ambient noise
 - Microphone setup
 - Instruments (Acoustic measurement instruments)
 - Measurement Positions (specify the height, distance etc.)
 - Pictures of the test setup
- Test Methodology
 - Duration of each test
 - Method of analysis
- Comprehensive Data Tables
 - Avg A-Weighted SPL values in all included measurement positions for all measured fan PWMs
 - [Optional] Max and Min A-Weighted SPL values if reporting
 - [Optional] Prominent Tone Identification and Tone-to-Noise Ratio Analysis

26.3 Mechanical

Fit Checks and analyses

- Tolerance Analysis of critical fit & mated connections; Tolerance Analysis for Slide Tension/Compression
- CTF dimension review of drawings
- FMEA of Hardware
- Inspection, Fit Check, FAI, & CPk data
- Quality Plan, including review of CM SOP, MSOP, Fixtures, Gauges, and Audit of factory lines

Shock & Vibration environmental tests

Equipment needed:

- Supplier-built test fixture to represent rack mounting within 11-OU based on the 3D CAD models provided for 1-OU sections of the Z2 and SH racks. To include busbars for operational Shock & Vibration tests.
- Z2 rack adapted to SH opening to be supplied by customer to the supplier to test with
- Equipment for functional verification tests before and after testing
 - Thermal loads?
 - Appropriate flow resistance simulators to be able to confirm functional performance of the CDU(s).
 - Visual inspection

- Fan functional
- Airflow dP vs flow
- Pump functional
- Pump dP vs flow
- Full system functional

Shock & Vibration Tests for each of the above. More details on the specifications for these environments are included in the Brazos Design Specification. Functional verifications during operational environments and after each non-op & transportation environment

- Operational shock, in 11-OU test fixture or Z2 rack
- Operational vibration, in 11-OU test fixture or Z2 rack
- HALT-like interconnect robustness, in 11-OU test fixture based on Z2 or SH rack section
- Bench handling drops - bare product for full chassis and each FRU
- Stability (tip tests), in Z2 rack
- Impact Rolling into a threshold, in Z2 rack
- Rolling off a threshold, in Z2 rack
- Transportation vibration (in crate), in Z2 rack and rack crate
- Transportation shock (drop testing in crate), in Z2 rack and rack crate
- Seismic

Configurations of racks for the above testing

- SH rack not provided, use 11-OU test fixture based on 3D CAD of SH rack section for operational tests only. Supplier to power the busbar externally.
- Z2 (adapted to SH opening) - Supplier to power the busbar externally, with 3x Brazos chassis in rack with 3OU gap beneath it.

Slide Safety Tests

- in 11-OU test fixtures based on Z2 and SH rack sections
- 1 minute with product weight plus an additional 300 lb load (at the center of the top surface of the chassis) without breaking
- 250 N static pull for 1 minute on an extended shelf to verify slide rail stops do not fail. Repeat for a total of 10 times.
- 250 N static lateral force for 1 minute applied to left and then right front edge of an extended shelf

Packaging Tests

- All Heavy FRU (> 35 lb) packaging to be HLA (Hardware Lift Assist) Compliant
 - Unpack w/o lifting - horizontal push/pull onto lift assist platform
- S&V Truck and Air Level II
- Package Drop Test

26.4 Power & electrical

- Validation at vendors
 - Board level
 - Voltage regulators (e.g., 3.3V VR)
 - Line and load regulation, output ripple, and transient response
 - Overcurrent, short-circuit, and thermal shutdown protection verification
 - Power conversion efficiency across operational load range
 - Hotswap circuit
 - Startup, start into short, overcurrent protection, short circuit protection, shut down
 - UVLO/OVLO
 - MOSFET SOA
 - Component temperature
 - Fans and pumps
 - Characterize input current during startup, steady-state, shutdown, speed change
 - Demonstration of intended FRU redundancy
 - Fan swaps
 - Pump swaps
 - Characterize inrush and transient rings during hot plug/unplug
 - System level
 - Input current & power consumption over full range of operational conditions
 - cooling load / back pressure
 - all mode transitions, including power up/down and RPM ramps
 - Power up/down sequence and timing of all rails
 - reported power telemetry accuracy and remote restart capability
 - Immunity to 48V input bus dV/dt events of +30V/ms, -10V/ms
 - Compliance to [conducted EMC](#) validation listed below.
 - In particular, surge test at both AC and DC input

26.5 Controls hardware

- Validation at vendors
 - Perform Electrical design verification on Signals measurement and test report
 - Provide the diagnostic software for each functional test and functional test report
 - Power and reset test
 - Clock test
 - Ethernet test
 - Memory test
 - Interfaces tests: SPI, SMBus, UART and etc
 - JTAG test

- HMI integration
 - Provide Manufacturing test plan and software
 - Provide the regression test and 4C (Voltage and temperature) test report

26.6 Controls & monitoring software

- Control module shall use DHCP to acquire an IPv4 address, including implementation of DHCP option 60 (Vendor class identifier) in the DHCP messages from the control module.

26.7 Safety

- Vendor shall obtain NRTL and CB certification to the latest edition of UL/CSA/IEC/EN 62368-1; Alternatively, if vendor has already obtained certification to UL/CSA/IEC/EN 60335-1 and UL/CSA/IEC/EN 60335-2-40, additional testing to cover IEC 62368-1, G.15 requirements are to be completed either separately or as a supplemental test report of the basic certification.
- Vendor shall share complete NRTL and CB test reports including all national deviations as specified in the most current CB Bulletin and certificates
- Vendor shall share EVT and DVT safety test plans and test results

26.8 EMC

- EMC tests must be performed on EVT and DVT builds and any builds that have changes that could impact EMC performance.
 - Testing on EVT build: to verify EVT units meets the EMC performance requirements.
 - Testing on DVT build: to perform formal EMC testing and obtain reports and certificates.
- EMC tests to be performed:
 - Radiated emissions, conducted emissions, ESD, EFT/B, conducted immunity, radiated immunity, magnetic immunity, surge.
 - Details about test levels, immunity criteria, pass/fail criteria will be documented and reviewed in the EMC test plan.

26.9 Compliance

- The Products shall be designed for compliance and obtain relevant certifications to allow worldwide deployment.
- EMC Laboratory shall meet the basic accreditation requirement by A2LA or NvLAP.
- When in-country testing is required, it is important for the vendor to ensure confidentiality of the Products when sent for in-country testing. Proper NDA shall be developed between the vendor and the selected test laboratory listed by the respective regulatory

- agency.
- Ensuring the complete compliance of the Products in the environment it is intended to function.
- Maintaining the certification of the Products which includes but is not limited to re-certification and/or any re-testing that may become required due to changes or revisions in the standards or regulatory requirements

26.10 Data Center Operations

- Installation / Removal
 - force required
 - Electrical connection DLRO
- Weight filled with coolant
 - Confirm that ServerLift can be used for installation
- Online hot swap FRU replacement
- Swapping aCDU
- Installing and swap rack manifolds
- Confirm alerts, alarms and monitoring are triggered in HMI or equivalent monitoring
- Physical testing: blind mate connection cycling between aCDU power connector and busbar, i.e. pull-in, pull-out testing
 - Qty 20 cycles, then measure electrical resistance and electrical functional testing
- Simulated deployment
 - Physical installation, swapping/decommissioning
 - Physical commissioning steps (filling, leak detection)
 - Physical service (topping off, sampling, hot swap FRU replacement)

26.11 Reliability

Reliability Testing shall be performed:

- on **all key components** at the piece part / assembly level.
- on the **full Brazos system**
- With DI water (priority) and PG25 (after testing with water is completed)

Pressure Testing

Pressure testing (cycling and burst) shall be performed on **all components that make contact with the coolant**. This includes:

- Filters
- Hoses and Hose Barbs
- Hot swappable redundant pumps
- Hot swappable redundant temperature & pressure sensors
- Liquid connections for charging & draining
- Liquid reservoir
- Rack Manifold assembly for Brazos

- Rack manifolds
- Radiator (Air-liquid heat exchanger)
- Stainless steel piping with Brazos

Tests shall be run with DI water and PG25 to reflect the use environment.

Pressure cycling, water hammer, and burst testing shall be performed as follows.

150 psi Pressure Test				
Step	Type	Value	Tolerance	Duration (min)
1	Dwell (psi)	0	± 5	0.4
2	Pressure ramp to 150 psi (psi/min)	83	± 3	0.5
3	Dwell (psi)	150	± 5	0.4
4	Pressure ramp down	83	± 3	0.5
5	Cycles	5000 of first failure		
Water Hammer Profile				
Step	Type	Value (psi)	Tolerance (psi)	Duration (sec)
1	Maintained water pressure (psi)	15	± 5	N/A
2	Hydraulic Shock (psi)	375	± 30	0.01
3	Hydraulic Dwell (sec)	0.01	0.005	N/A
4	Cycles	10,000		

Table 26.1: Pressure cycling, water hammer, and burst testing requirements

Component Level - Sample Sizes and checks for Pressure Testing

Test	samples to test	Notes
Helium Leak Check	3	50 psig helium sweep. Helium leak rate must be < 1.0x10 ⁻⁵ atm cc/sec.
Hydrostatic Leak Check	3	pressurized to 150 psig and inspected for signs of water leaks
High Pressure	3	pressurized to 500 psig or failure, whichever comes first.
Pressure Cycle	8	-300 psig, 1 min/cycle, for 5000 cycles with 1 hr, 150 psig hydrostatic tests every 1000 cycles.

Water Hammer	8	Each sample is subjected to cycles of 15-375 psig, 2 seconds/cycle for 10,000 cycles. If max pressure of part is found to be <300 psig during high pressure testing, cycle pressure will be reduced to 150 psig.
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Table 26.2: Component level sample sizes and requirements for pressure testing**Full Brazos System - Sample Sizes and checks for Pressure Testing**

Test	samples to test	Notes
Helium Leak Check	3 Brazos systems at EVT	50 psig helium sweep. Helium leak rate must be < 1.0x10 ⁻⁵ atm cc/sec.
Hydrostatic Leak Check	3 Brazos systems at DVT	pressurized to 150 psig and inspected for signs of water leaks
Pressure Cycle	3 Brazos systems at PVT	-300 psig, 1 min/cycle, for 5000 cycles with 1 hr, 150 psig hydrostatic tests every 1000 cycles.
Nitrogen Pressure Decay test	Same as above	Pressurize at 10 psig, place in storage and measure pressure at time =0, 1 month, 2 months, 3 months, 6 months, 9 months, 12 months

Table 26.3: Full system sample sizes and requirements for pressure testing

Brazos Rack Manifold Reliability Testing

Test	Name	Description	Sample Size Per Design	Pass Criteria
1	Buildup assembly at Brazos supplier	Assembly at Brazos supplier	4 assemblies, 8 sticks	Able to assemble with POR hardware
2	Cross Section inspection	Send new 4 port geometry to Welding Consultant	One 4-port sample	Approval from Welding Consultant
3	Pressure Cycle Test	2 x maximum pressure rating of the system	4 assemblies	Pass if no leak after 5k cycles
4	Water Hammer	Hydraulic Shock Test	4 assemblies	No leaks
5	Burst Pressure	Destructive testing	2 Assemblies	N/A
6	Transportation Testing		1 full crate	See Specification section on Packaged Transportation Testing

Table 26.4: Rack manifold sample sizes and requirements for pressure testing**Radiator Reliability Testing**

Radiators shall be **subjected to the same tests (and required sample sizes) as Rack Manifolds (see section above)**. In addition, salt spray testing shall be performed to ASTM B117-11 (5% NaCl, pH: 6.5-7.2, Test chamber temperature:35C Saturated air barrel temperature:47C, Continuous spray for 48H). Sample size for salt spray is n=1.

Hoses / Hose barbs - Reliability Testing

Hoses with hose barbs attached should be subjected

1. Test 1000 cycles at 0 to 150 psi
2. Test 1000 cycles at 0 to 300 psi
3. Then test to failure

Additional tests include:

- [Flammability test](#)
- Hose impulse test
- Hose pull (Lateral & Axial)
- Inspection of hose (near hose barb) after pressure cycling

- Pressure burst test (300 psi, 5 min) and pressure burst limit test
- Pressure cycling test (0-150 psi, 1000 cycle)
- Storage test (high and low temperature)
- Thermal cycling test

Fan Reliability Testing

It is expected that Brazos suppliers choose fan suppliers and fan models with a proven reliability record. Brazo's suppliers should assess both the **larger** fans (Brazos fan array) and **smaller** fans, such as those on a pump drive housing (VFD).

Reliability Data collected at Fan Supplier

Brazos' suppliers shall provide reliability data collected by the fan supplier.

This includes

- L10 data (tested at 70C) and MTTF calculations (see table below)
- The data from the full test suite performed by the fan supplier, including acoustic test data as function of fan age.

Testing Goal	Operating Temperature (C)	Test Temperature (C)	Sample Size Individual fans
L10 = 50,000 hr	40	70	32
MTTF = 100,000 hr	40	70	32

Table 26.5: Fan reliability requirements

Fan Reliability data collected at Brazos supplier

Brazos Suppliers should develop a test to assess the impact of failed fans on the overall fan array. For example, if one fan fails, will backflow of air occur, and the fan will spin backwards? Is there a system to detect failed fans? How many fans can fail before Brazos performance is impacted.

System / boards PCBA Reliability Testing

Perform PCBA standard environmental chamber test -- One board of each type at EVT, DVT, PVT:

- HAST (85 C / 85% Humidity)
- High temperature operating life test, test at temp and voltage at operating limits for 1000 hours
- Power thermal cycle test, zero to full load (min to max operating temperature)

limits of product). Constant load during thermal cycling ... with power cycle included periodically.

Test functionality of PCBA before and after environmental test.

Pump Reliability Testing

(1) Repeated off-on-plateau test

This test is designed to simulate the “wear and tear” on pump bearings when the pump is turned on and off, which might occur a few times per year to clean the coolant filters.

(2) Marathon test

This test is long term pump test at 100% pump speed lasting at least one year, and is designed to assess “wear and tear” and pump and pump drive (VFD) longevity

(3) Thermal stress test

This test will be designed in such a way that the Pump (Stator coils) and VFD (PCBA) will experience the maximum internal temperature due to heat generated by a heavy workload (high pump power, high hydrostatic resistance). The test should be run such that any cooling fans on the VFD are in continuous operation. This test is designed to detect and temperature related failure mechanisms on the PCBA, Stator or cooling fan bearings

		Repeated off-on test with plateau		Marathon test		Thermal Stress Test on Pump + VFD (Worst Case)		Total number of pumps & VFDs
		Off --> 100% speed 10 min --> spin down to 0 RPM, wait 30 seconds, repeat 100x		Steady state operation ... least 1 year of continuous operation at 100% speed		Adjust the pump speed to 100% and adjust the flow impedance so that the VDF fan is CONTINUOUSLY “on”		
	Working Fluid	Sample size (n)	Possible Failure Mode	Sample size (n)	Possible Failure Mode	Sample size (n)	Possible Failure Mode	
Brazos	Water (Coolant)	3	Wear and tear on bearings	3	TBD	3	PCBA failure. Fan failure	9
	PG-25	3	Wear and tear on bearings	3	TBD	3	PCBA failure. Fan failure	9

Table 26.6: Pump reliability testing requirements

Hot Swapping of Pumps - Reliability testing

Hot swapping of pumps should be an event that should rarely occur. It is critical that the:

- (a) The connection not leak
- (b) The pump be easily removable (with no ergonomic issues)

Repeated attach detach test

The purpose is to ensure the mechanical latching mechanism and seal remain stable after multiple attach and detach cycles. Test should be in dry condition (not fluid in the system) to obtain accurate helium leak reading after testing

Repeated attach detach test	Helium Leakage rate	Sample size (n)	Comment
0 cycles	measure value	3 pumps	Measure with Helium sniffer
100 cycles	measure value		
250 cycles	measure value		
500 cycles	measure value		

Table 26.7: Pump connection testing requirements**Ergonomics**

The force required by a technician to swap out a pump will depend on the type of connection and possibly the pressure. This test will measure the ergonomic forces, and determine if the forces increase after pressure cycling on the system

		Maximum ergonomic force to swap pump at fluid pressure of:		
	Sample size	0 psig	50 psig	100 psig
PRE - Pressure cycle testing	3 pumps	measure value	measure value	measure value
POST - Pressure cycle testing		measure value	measure value	measure value

Table 26.8: Pump swap ergonomic testing requirements**Quick Disconnect Tests**

Reliability testing of the entire rack manifold assembly will automatically cover reliability testing of the Quick Disconnects (QD)

Quick disconnect testing may include:

- Pressure tests (burst testing, 500 psi)
- Pressure impulse testing (10,000 cycles at 500 psi)
- Flow tests (pressure drop and surge flow testing)
- Connection testing (2000 to 5000 cycles)
- Helium Leak testing
- Aging tests (disconnected state)

26.12 Manufacturing Cpk

Liquid Cooling System Manufacturing Qualification Outline (Milestones)

Gate	Item	Objective	Build Plan and Min Qty	ECD & Result	Notes
EVT	Complete DFM, DFA, PFMEA, PMP, Hose Connection Testing for Tension and Shear (Max and Leak Limit), Connector Testing, New Component Evaluation, First Pass Yield	Determine design and assy optimizations, determine process risks, FPY >75%	EVT, 3-5 systems (pending) - 3-5 pcs FAI - Functional Test Data, 3-5 pcs - Leak Testing, 3-5 pcs - Assembly Evaluation, 3-5 pcs - Shock and Vibe, *1-3* pcs		
DVT	Component FAI & CpK, Thermal Performance Data, Hose Connection Testing for Tension and Shear (Max and Leak Limit), Connector Testing, Implement MES and Traceability, Spec Validation/Corner Case Builds, Piece Part Tolerance Validation, First Pass Yield	Establish initial equipment and process capability for piece parts and assembly. Determine Mechanical Corner Cases OK from Assy Stack. RCCA Failures and Process Defects. Define SPC Charts. Targets: FAI All Pass, CpK >0.5, FPY >90% Establish IPQC	DVT, 3-5 systems - 3 pcs FAI, 32 pcs Cpk - Functional Test Data, 100% - Leak Testing, 100% - DC Initial Qual - 3-5 systems - Assy Evaluation, 100%		
PVT	Spec Validation/Corner Case Builds, Piece Part Tolerance Validation, FAI & CpK Data, Thermal Performance	Establish initial equipment and process capability. Check for corner cases. RCCA Failures and Process Defects. Define SPC Charts. Targets:	PVT - 10-20 systems - 3 pcs FAI, 32 pcs Cpk - 100% Functional Test Data across different days/shifts - 100% Leak Testing - 32 pcs long term storage/pressure drop		

	Data, IPQC Data, OQC Data, First Pass Yield	FAI All Pass, CpK >1.0, FPY > 99%	testing (as required) - SPC across different days/shifts - Assy Evaluation, 100%		
Ramp	FAI & CpK Data, Thermal Performance Data, IPQC Data, OQC Data, First Pass Yield	Ramp production, check for corner cases, FOD. RCCA Failures and Process Defects. Check SPC Charts. Targets: FAI All Pass, CpK >0.5, FPY > 99%	Ramp - 20-30 systems - 32 pcs FAI, CpK - 100% Functional Test Data across different days/shifts - 100% Leak Testing - SPC across different days/shifts		

Table 26.9: Manufacturing qualification requirements

Liquid Cooling System Manufacturing Qualification Plan

Test Description (at Vendor)	Target/Objective	Qty	Destructive Test	Test Duration (historical)	ECD
Dimensional - FAI & CpK	EVT: CpK >0.5 DVT: CpK > 1 PVT: CpK > 1	8-32	No	< 3 days	
Cross Fixture/Machine Qual	Find Failures Line Failures	8-32	No	< 1 week	
Braze or Weld Analysis (Metallography, X-Ray, CT Scan, Penetrant Dye, Microscopy)	Find Process Failures	1-3	No	< 3 days	
Fixture Poka-Yoke Check	Verify Function	3-5	No	< 3 days	
Test Equipment Expanded GR&R	Qual Measurement Equipment	5 samples x 3 operators	No	< 3 days	
Fault Injection into Check Fixtures and Test Equipment	Verify Function	1	No	< 3 days	

Traceability NG Part Gate Check	Verify Function	1	No	<1 Day	
Outgoing Quality Control data from production line test equipment (N2 high pressure test (max operating pressure per product specification), He leak, Functional Test (Thermal, Flow, Pressure Drop)	EVT: CpK > 0.5 DVT: CpK > 1 PVT: CpK > 1	8-32	No	<3 Days	
Control Build for mechanical fit check in machine trays or data center clusters	Verify System Fit/Function	1 system	No	< 2 weeks	
FPY Over 98%	Verify Yield	8+	No	< 2 Weeks	

Table 26.10: System manufacturing qualification requirements

Appendix

Appendix A: Glossary of terms

aCDU: Air-Assisted Coolant Distribution Unit

CDU: Coolant Distribution Unit

DVT: Design Validation Test

EVT: Engineering Validation Test

FRU: Field Replaceable Unit

HMI: Human Machine Interface

PLC: Programmable Logic Controller

PVT: Production Validation Test

PWM: Pulse Width Modulation

UUT: Unit Under Test