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CarboNIX
User Manual

Microsatellite separation system
Revision 2.2 | June 2024

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Version	Author	Date	Changes
1.0	CP	27 May 2022	Initial release of combined CarboNIX User Manual for all CarboNIX sizes and configurations.
2.0	CP	06 Sep 2022	New Document Design
2.1	TS, CP, MT	06 Mar 2024	Added CarboNIX 11.732, updated values and pictures, corrected typos. Updated mass properties, stiffness values, interface drawings. Updated Max Load and Stiffness guidelines in section 3.6. Updated FE modelling guidelines in section 3.7. Updated electrical interface information (continuity checks) in section 3.12.
2.2	MT	13 June 2024	Updated C11.732 info in Table 3 and Table 4 Updated allowable baseplate protrusion dimensions in Table 4 Added section 3.7 Dynamic Simulators Updated electrical signal characteristics in section 3.13.2 Added details to section 4.1.3, 4.2.4, 4.2.5

Quick Reference

Figure 1:
CarboNIX Coordinate System

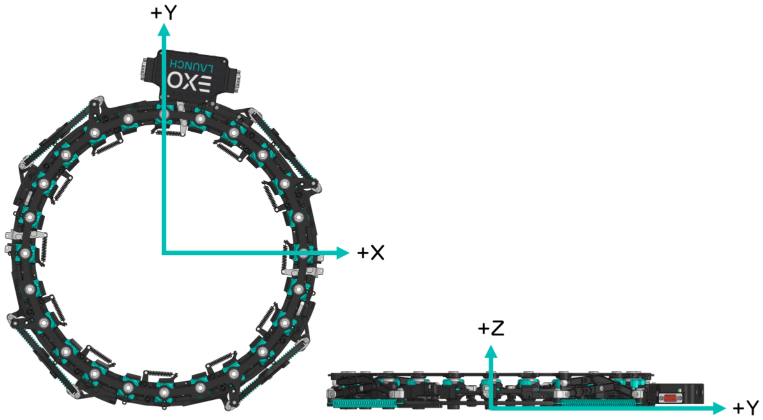


Table 1: CarboNIX Characteristics Overview.

Parameter		Section	C8	C11.732	C15	C18.25	C24
Mounting Pattern	Bolt Circle Diameter [mm]	3.4	203.20	297.99	381.00	463.55	609.60
	Bolt Circle Diameter [in]		8.00	11.732	15.00	18.25	24.00
	Number of Fasteners		12	18	24	28	36
	Fastener Type		M6 or 1/4-28				
	Flatness Tolerance [mm]		0.10				
Keep-Out Dimensions [mm]	Inner keep-out diameter [mm]	3.5	130	233	310	395	545
	Outer keep-out diameter [mm]		300	394	475	560	700
Mass [kg]	S-Ring ST [kg]	3.2	0.23	0.34	0.43	0.51	0.63
	S-Ring IM [kg]		0.27	0.39	0.51	0.59	0.74
	L-Ring [kg]		1.52	2.01	2.52	2.95	3.64
Separation	Nominal Separation Signal	-	28VDC for 0.5s				
	Average Separation Time [s]		0.10				
Thermal [°C]	Lower Operating Limit	-	- 34				
	Upper Operating Limit		+71				
	Lower Survival Limit		- 55				
	Upper Survival Limit		+130				

2

Introduction

2.1 What is CarboNIX

CarboNIX is a family of separation systems for small satellites up to 500 kg. Since the first CarboNIX demonstration on orbit in 2019, CarboNIX has deployed over 70 customer satellites to orbit. CarboNIX users include the undisputed leaders in the smallsat industry, including Planet, Iceye, Satellogic, NanoAvionics and Loft Orbital.

CarboNIX uses shock-free technology to reduce the risk of damaging sensitive satellite optical payloads and electronic components. CarboNIX also uses a unique spring pusher system which separates the satellite before the shocks are generated. This means that all shock forces can only reach the spacecraft by traveling through the linkages, and since shock forces are attenuated by joints and distance, the shock loads that reach the spacecraft are substantially reduced. In addition, every pusher arm in the spring pusher system is linked together and moves at the same velocity, guaranteeing a tip-off rate of less than 2 deg/s regardless of the location of the satellite Center of Gravity. All these features make CarboNIX the most advanced separation system ever used in space.

The unique design gives CarboNIX best-in-class compatibility with satellites and launch vehicles while delivered unparalleled reliability and performance. CarboNIX is currently available in 8", 11.732", 15", 18.25" and 24" versions and can also be designed to custom sizes to meet your needs. Contact Exolaunch for details.

Figure 2: Available CarboNIX Sizes.

CarboNIX is also designed and manufactured entirely within Europe, meaning it is not subject to strict export regulations such as ITAR. This reduces the cost and complexity of using CarboNIX and allows it to fly on any launcher in the world.

CarboNIX is manufactured using only COTS components. As with all Exolaunch technology, CarboNIX is manufactured in Germany in a facility certified to ISO 9001:2015 standard, which requires regular inspection of the manufacturing and assembly facilities and ensures a stable quality of the final product. These same quality standards are applied to the qualification and acceptance testing processes.

CarboNIX has some unique advantages over other microsatellite separation systems

- **Flight Heritage.** CarboNIX has deployed 86 customer satellites for industry-leading customers in Europe and the US.
- **Fast Integration and Reset Time.** The whole system can be triggered and reset in minutes. Constellation customers benefit from fast and consistent processing times at the launch site when launching multiple satellites.
- **Shock-Free Separation.** Very low shocks are generated during separation, making it very gentle on delicate satellite components. Relative to other separation systems on the market CarboNIX is virtually shock-free.
- **Low Tip-Off Rates.** The average tip-off rate is less than 0.6 deg/s in all three axes. No tip-off rate higher than 2 deg/s has ever been recorded in space.
- **Licensing.** Operating CarboNIX does not require expensive training and licensing.
- **Lightweight.** The CarboNIX flyaway mass is half that of other's separation systems of the same diameter.
- **Scalable.** The unique design centered around a single clamp element which is repeated along the circumference, allows CarboNIX to be easily scaled to different sizes.
- **Flexible.** CarboNIX can be used with and adapted to any launch vehicle.
- **Compact.** In the stowed state, CarboNIX is less than 50 mm thick.

Figure 3:
Four CarboNIX 15 L-Rings mounted on an EXOport Adapter and ready for microsat integration on the SpaceX Transporter-2 mission.

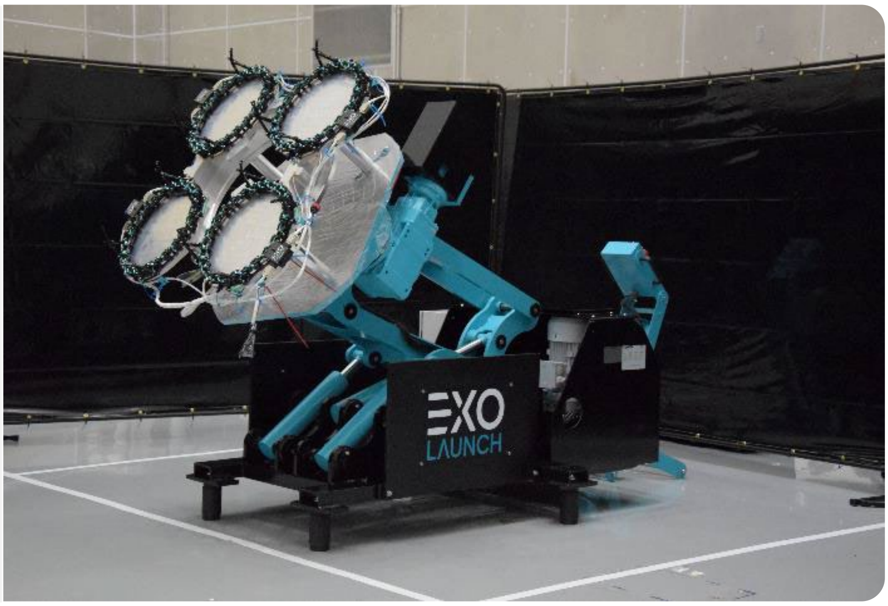


Figure 4:
Three CarboNIX 15 units were used on the June 13, 2020 SpaceX Starlink-9 Rideshare Mission. Each SkySat had a mass of 110 kg.

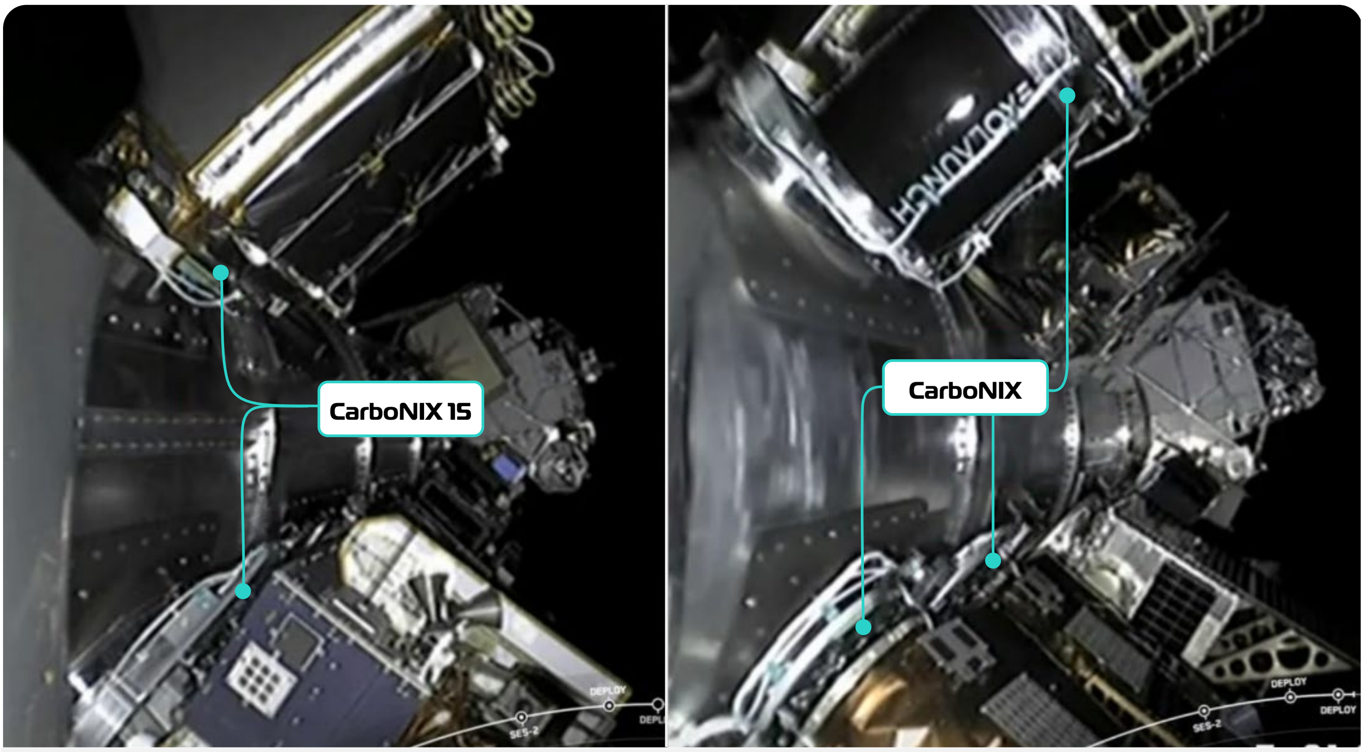
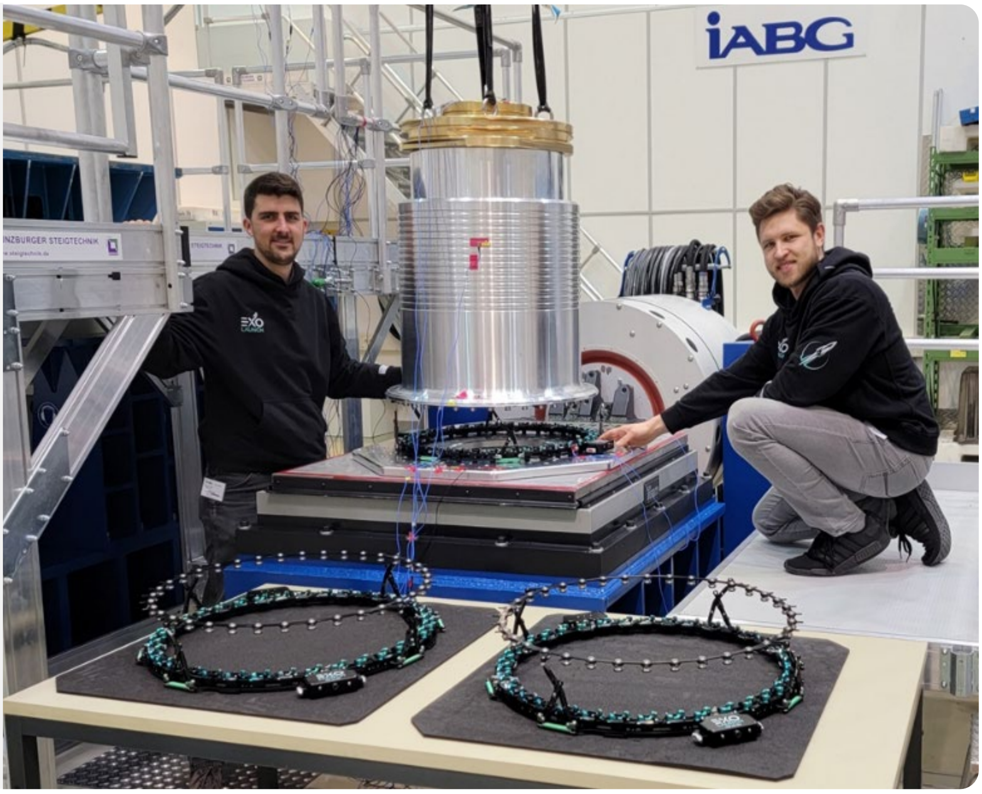


Figure 5: Ten CarboNIX 15's successfully deployed on the SpaceX Transporter-2 Mission in July 2021.

Figure 6: Four CarboNIX 15s sharing a plate with EXOpod Novas and ready to launch on Transporter-8.

Figure 7:
Three CarboNIX 24 units undergoing qualification testing.



2.2 Qualification Status

CarboNIX has a TRL of 9 and has flight heritage on multiple launch vehicles. By far, the most common launch configuration is on the Falcon 9 Transporter missions, where the CarboNIX is mounted in the "wall-mounted" configuration. Contact Exolaunch for details and launch opportunities.

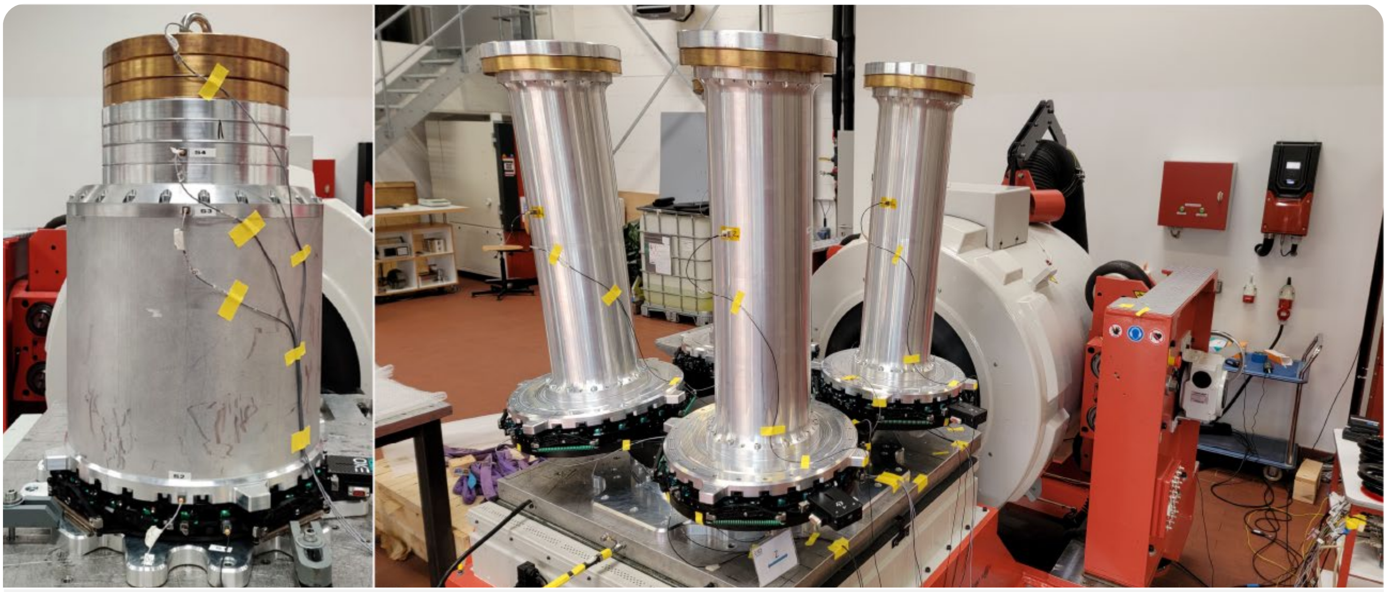
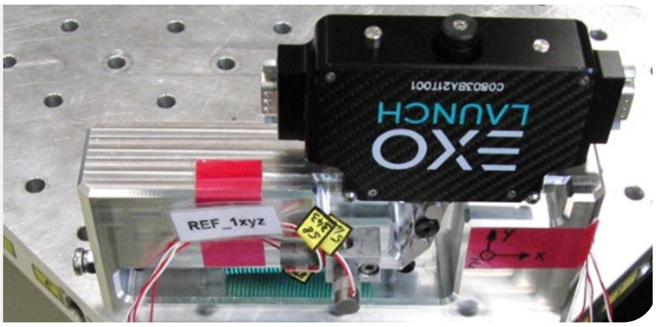


Figure 8: CarboNIX 15" qualification testing (left). Four CarboNIX 15" on an EXOport adapter (right).

The CarboNIX lock mechanism is the only shock-sensitive element of the CarboNIX system. It has been qualified for environments up to 2000g shock loads at 1 kHz and 5000g at 10 kHz, both in a standalone lock mechanism test and in an integrated lock mechanism system test.

Figure 9:
Lock Mechanism Shock Testing.



2.3 Components and Features

The main components of the CarboNIX separation system are shown in the figure below.

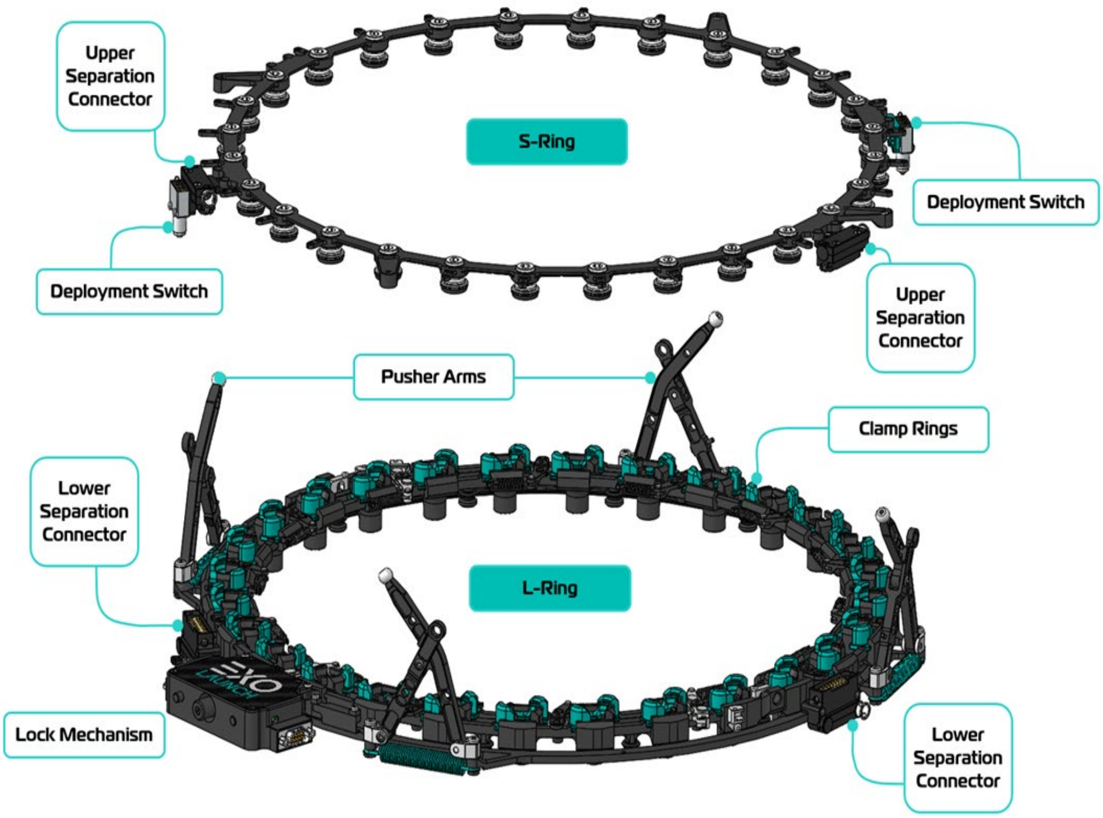


Figure 10: Main Components of the CarboNIX Separation System.

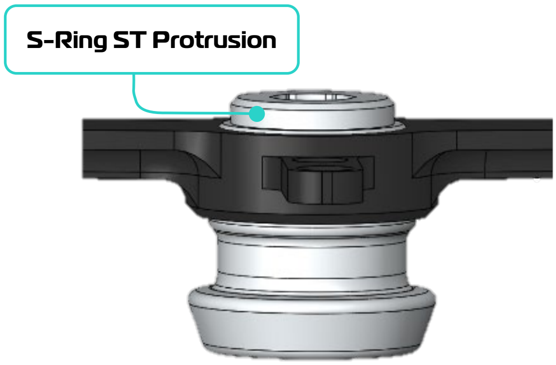
2.3.1 S-Ring

The S-Ring is the part of CarboNIX that is attached to the satellite. It is fastened to the bottom of the satellite using either M6 or 1/4-28 screws in a circular pattern. It comes in two variants: S-Ring ST and S-Ring IM. The S-Ring ST is the standard configuration, and it has the lowest flyaway mass of any microsatellite separation system.

Figure 11:
CarboNIX S-Ring

The S-Ring ST is able to achieve such an incredibly low weight due to its unique protrusions at each of the screw mounting points. These protrusions relieve the mounting fasteners of having to withstand shear loads during launch. A corresponding counterbore feature is required on the satellite base plate to be compatible.

Figure 12:
S-Ring ST Protrusions



For customers that have designed their satellite to accommodate clamp-band style separation systems, the S-Ring IM has been designed to match this interface so that no changes to the satellite are required. The S-Ring IM is about 25% heavier compared to the ST.

Figure 13:
CarboNIX S-Ring IM

2.3.2 S-Ring Cable Tie Mounts

The S-Ring has cable tie mounts located on the circumference of the ring to assist with harness routing. Harness may be routed both above or below the cable tie mounts; above and outside the mounts is preferred. **NOTE:** Harness routing may not pass over the lock mechanism box.

Figure 14:
Cable Tie Locations on the S-Ring

2.3.3 L-Ring

The L-Ring is the portion of the separation system that stays attached to the launch vehicle after separation. It is mechanically and electrically connected to the launch vehicle adapter. It can be fastened to the launch vehicle with either ¼-28 or M6 screws.

Figure 15:
CarboNIX L-Ring

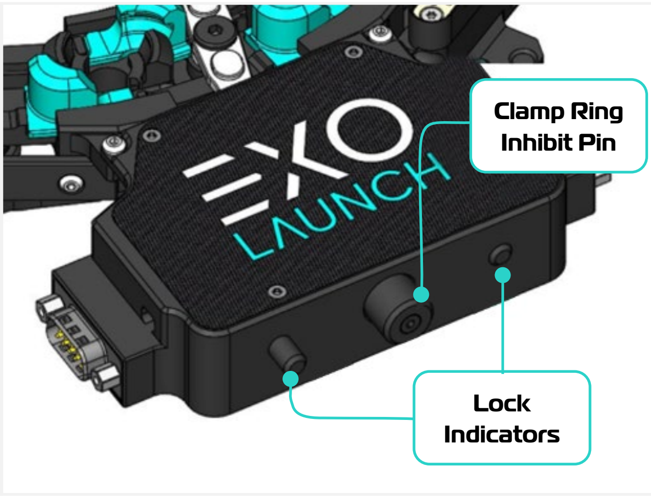
2.3.3.1 Lock Mechanism

The locking mechanism uses a unique magnetic system that can be released either using an electrical input signal from the launch vehicle, or from the Exolaunch electronic sequencer unit EXObox. The lock allows quick integration and de-integration within minutes. For maximum reliability, CarboNIX uses redundant locks that can trigger the opening independently from separate deployment signal channels.

There are two elements of the lock mechanism, the Clamp Ring Inhibit Pin and the magnetic locks, which are toggled by pushing in the lock indicators. Operating instructions for the lock mechanism can be found in Section 4.2.5.

The locking mechanism receives the firing signal through one of two 9-pin D-Sub ports. As needed, either one or both of these ports can be used for redundancy during the mission.

Figure 16:
CarboNIX Lock Mechanism



2.3.3.2 Lock Rings

The S-Ring is secured to the L-Ring using the lock ring assembly, which consists of two contra-rotating clamping rings. In the stowed configuration, these rings grip the feet of the S-Ring and prevent any movement. Once the lock mechanism releases, the springs rotate the rings apart, unclamping and releasing the S-Ring.

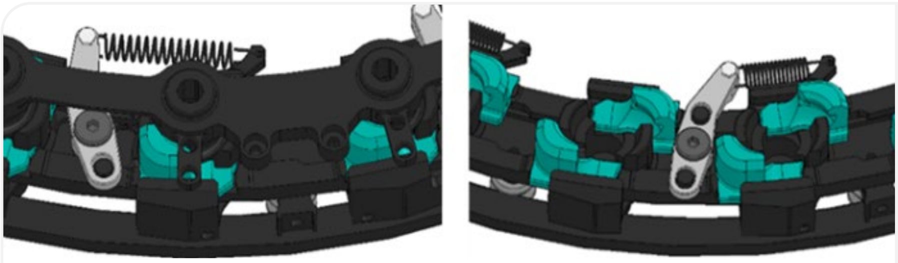
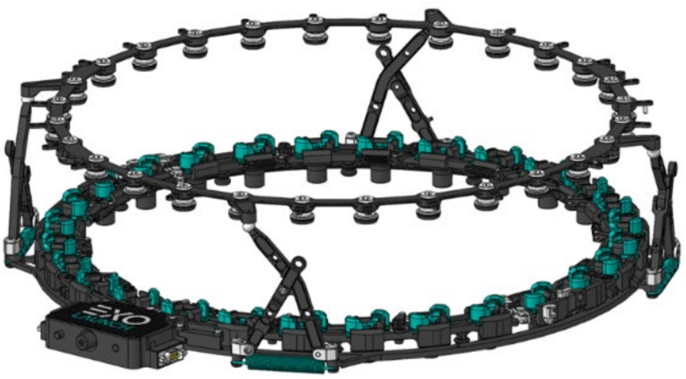


Figure 17:
Left, S-Ring is Securely Clamped to L-Ring. Right, S-Ring Released

2.3.3.3 Pusher Mechanism

Once the S-Ring has been released, the pusher mechanism creates the separation velocity between the launch vehicle and the satellite. This is done by three or four equally spaced pusher arms located external to the rings, as shown below. Each pusher mechanism is fitted with a starter spring on the lower arm. This provides the initial force to begin the separation, as the main separation springs are at a very oblique angle when stowed.

Figure 18:
CarboNIX in the Deployed State



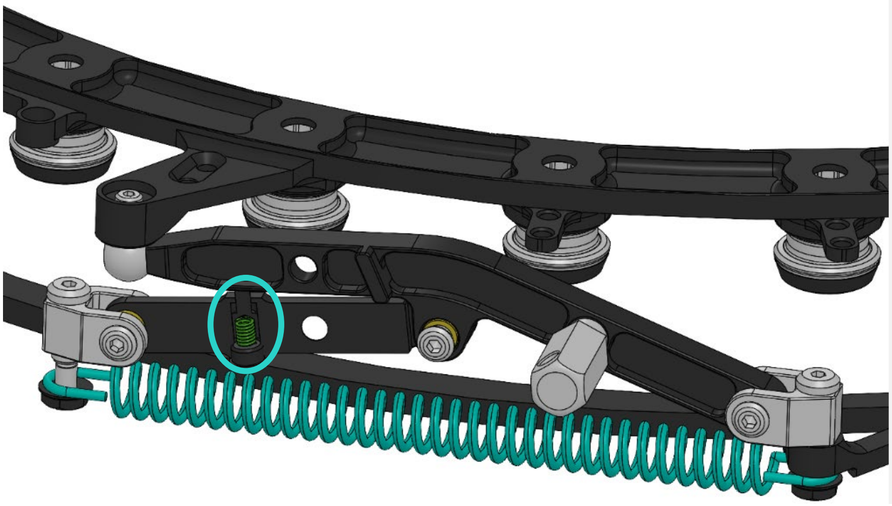
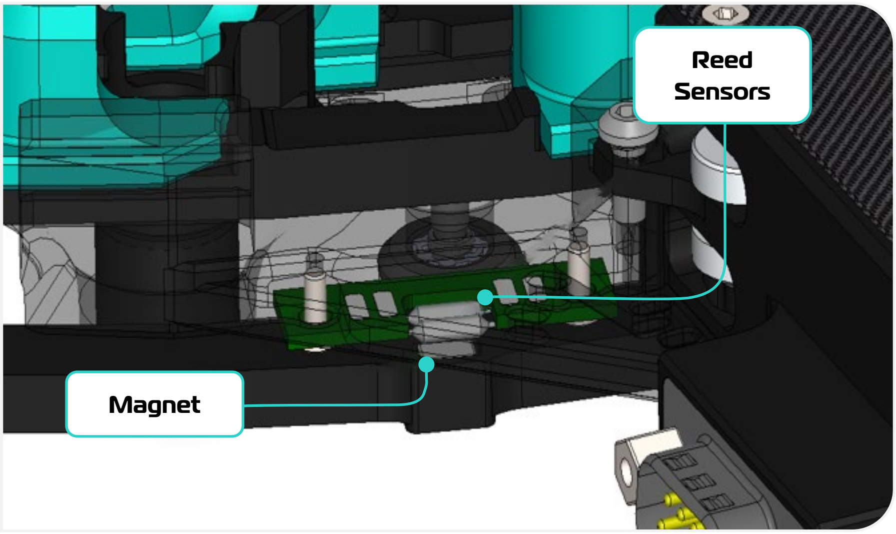


Figure 19:
A pusher arm in the stowed position.
The starter spring is highlighted.

2.3.3.4 Deployment Sensors

The CarboNIX has built-in deployment sensors which transmit the deployment status back to the launch vehicle. Deployment sensors are located in two positions. These sensors indicate whether the locking mechanism has been opened, and whether the pushing mechanism has been successfully deployed. In each position, there are two sensors for redundancy. The switch status is transmitted to the launch vehicle through the lock mechanism connector. The customer does not need to dedicate separation switches or breakwire loops in order to satisfy launch vehicle telemetry requirements.

Figure 20:
A magnet on the pusher mechanism ring activates two reed sensors.



2.3.4 Separation Switch

Customers may choose to mount one or several separation switches on the S-Ring in order to communicate the separation event to the satellite. These ITW 65-401000 switches are extremely rugged and have extensive flight heritage. The "over-travel" actuator ensures that the switch will not toggle until full separation has occurred.

Separation switches are for satellite-side telemetry only. Launch vehicle-side telemetry shall be transmitted through the built-in deployment sensors.

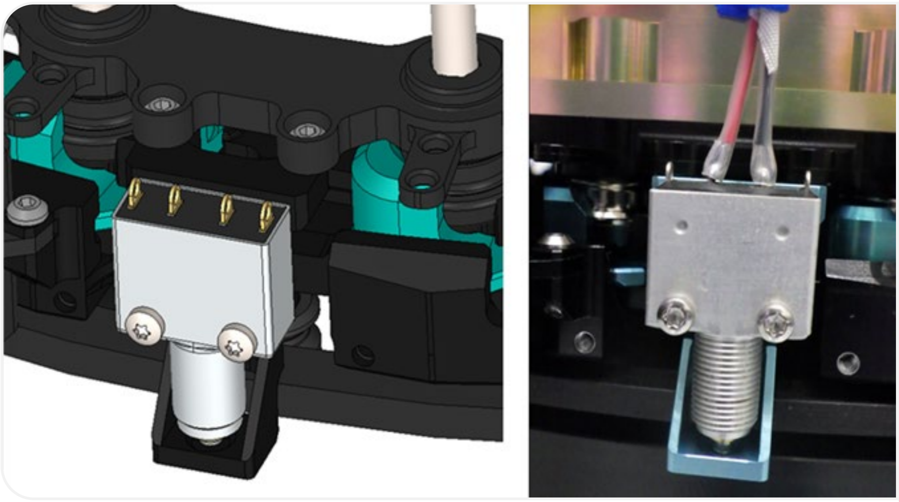


Figure 21:
CarboNIX Separation Switch.

2.3.5 Separation Connector

The separation connector can be used to provide an electrical connection to the satellite after it has been integrated on the launch vehicle. It can be used to charge the satellite batteries, satellite-side separation telemetry through breakwires, or to otherwise connect with the satellite after encapsulation. Separation connectors are for satellite-side telemetry only. Launch vehicle side telemetry shall be transmitted through the built-in deployment sensors.

Figure 22:
CarboNIX separation connector.
The green arrows show possible harness routing directions.

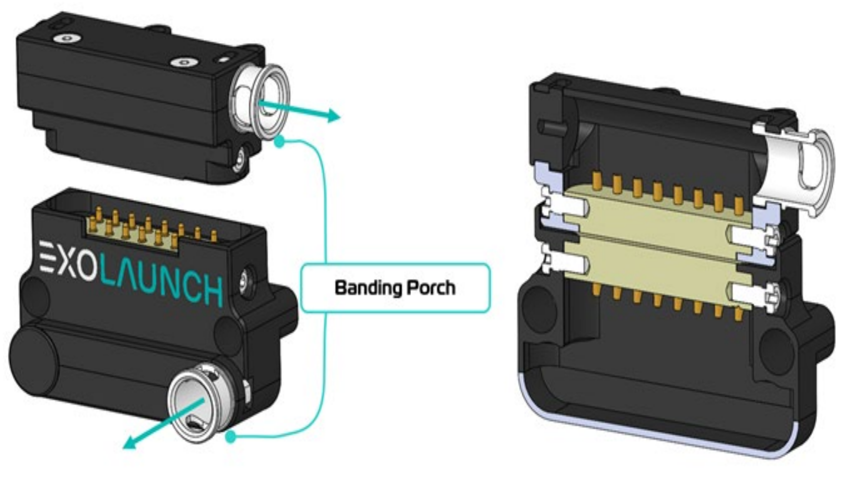
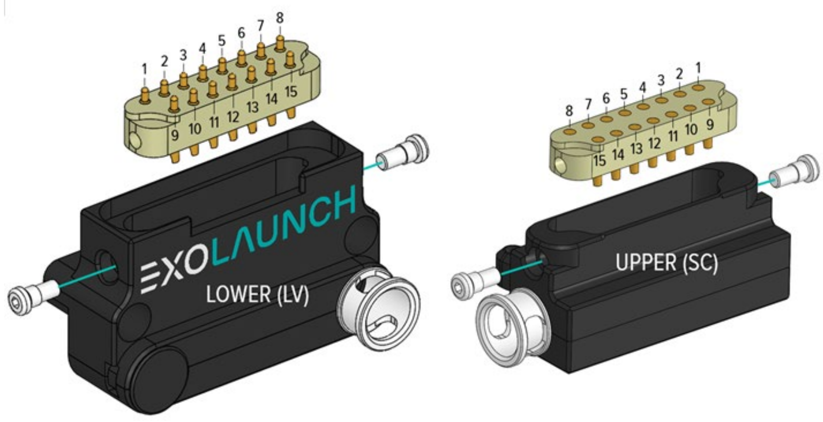


Figure 23:
CarboNIX separation connector, pin configuration.



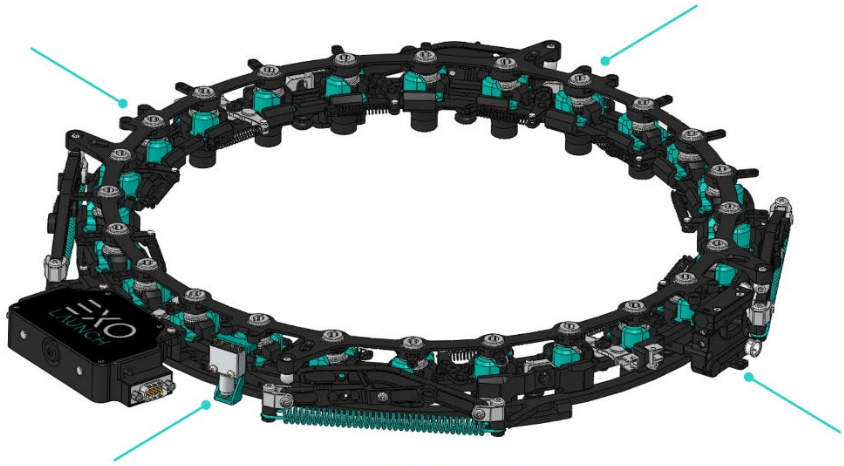
The separation connector can be used for a variety of mission scenarios, such as charging batteries after payload fairing encapsulation or activating the satellite before separation.

Note: **All electrical interfaces must adhere to limitations determined by the launch authority.**

2.3.6 Separation Switch and Connector Clocking

The separation switch and separation connector can each be connected to CarboNIX at one of four separate locations around the outside of the ring. Only three of these interfaces are available on the CarboNIX 8" and CarboNIX 11.732". This provides flexibility in harness routing for the satellite designer. Harness routing shall not pass over the lock mechanism.

Figure 24:
CarboNIX Separation Connector and Separation Switch Locations.



2.3.7 Harness Routing on the S-Ring

To simplify launch site operations, Exolaunch recommends incorporating separation switches and connectors with pigtail connectors, as shown below in Figure 25. This allows the harness to be routed along the S-Ring before it is installed on the satellite base plate so that access is optimized. This connector shall be located outside of the S-Ring; routing through the CarboNIX is not permitted.

The image below shows a Micro DSub-9 connector as an example. Satellite manufacturers are encouraged to select the connector of their choice when manufacturing the pigtail.

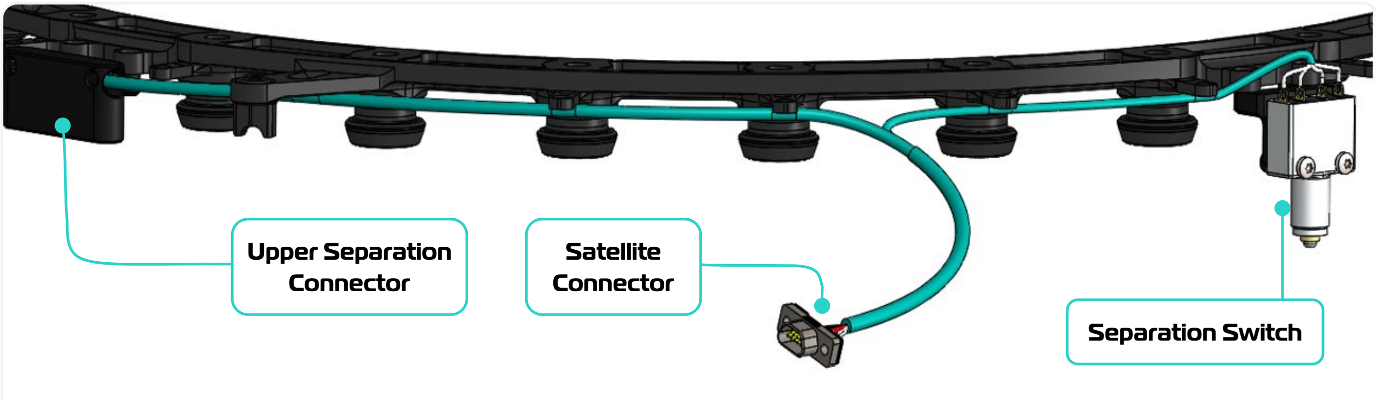


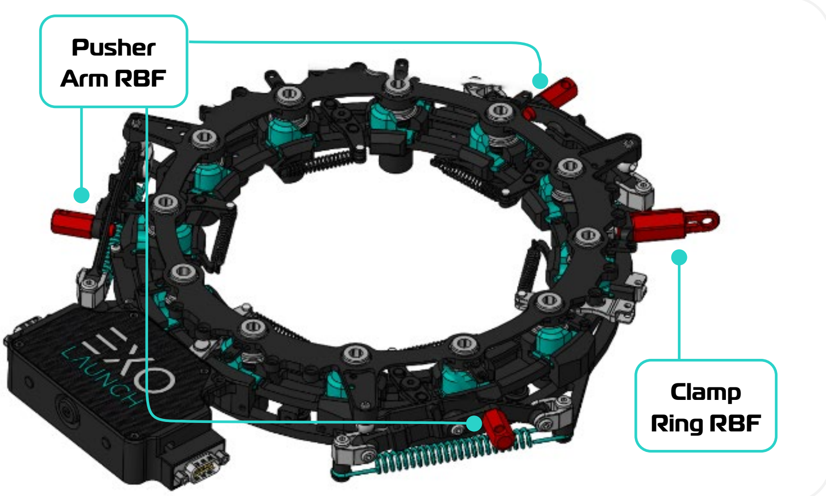
Figure 25:
Example of Pigtail Connector (e.g. Micro DSub-9) Incorporated with a CarboNIX Upper Separation Connector and Separation Switch.

2.3.8 Remove Before Flight (RBF) Elements

CarboNIX uses two types of RBF elements. Two pins are used to secure the clamping rings in the closed position and prevent accidental release of the S-Ring. Four additional pins are used to secure the pusher arms in the down position, which is useful for securing the arms while locking the S-Ring to the L-Ring.

Finally, a tool is used to engage the system, closing the clamping mechanism and securing the locks in place.

Figure 26:
CarboNIX with all RBF Elements highlighted in red. The CarboNIX 8 (shown) has only three pusher arm RBFs and one clamp ring RBF due to its small size.



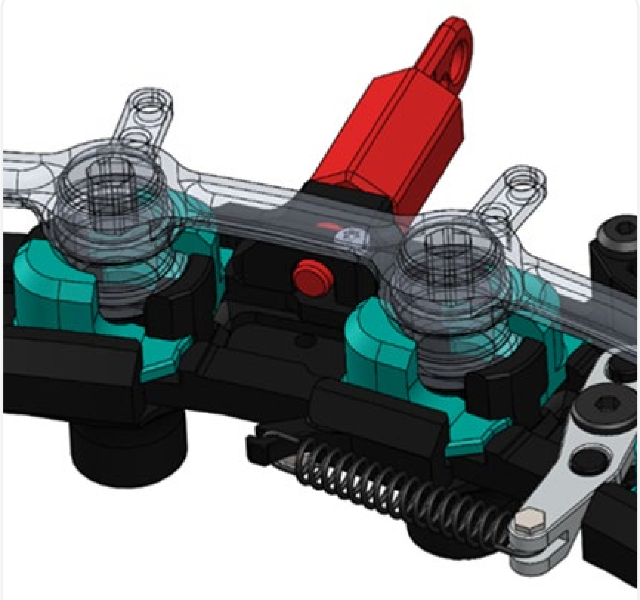


Figure 27: Clamping Mechanism RBF Prevents the S-Ring from Coming Loose.

Figure 28: Pushing Mechanism RBF Binds Two Arms Together and Prevents Deployment.

The clamp ring RBF has a spring-loaded pin which allows it to be inserted before the clamp rings are engaged. This can simplify the integration process, as the RBF will automatically lock the system shut once the clamp rings are closed. The red indicator on the RBF provides a visual indication of the status of the clamp rings. A single clamp ring RBF is sufficient to fully secure the system.

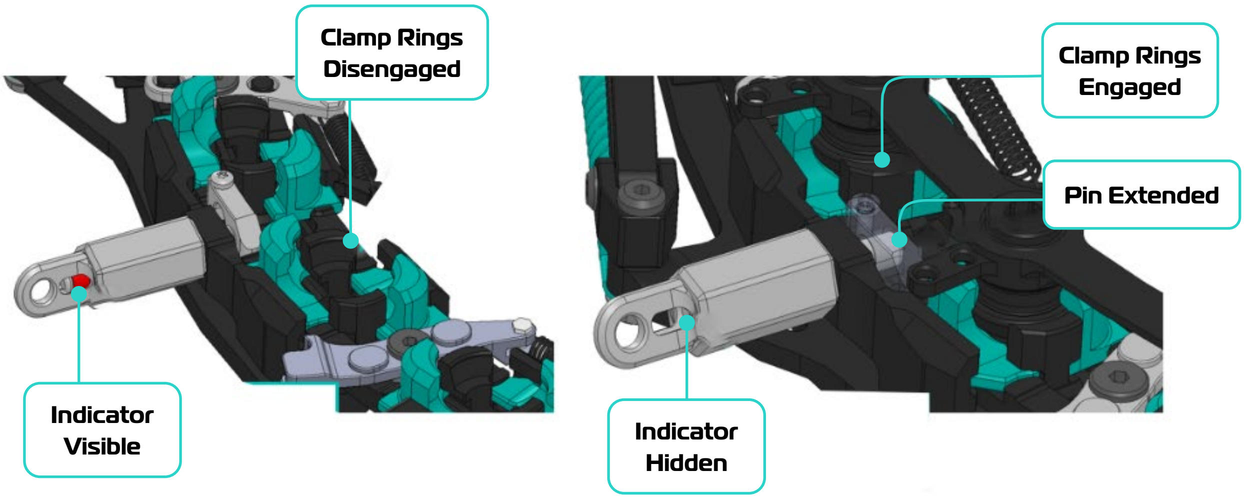


Figure 29: Clamp Ring RBF Function.

3

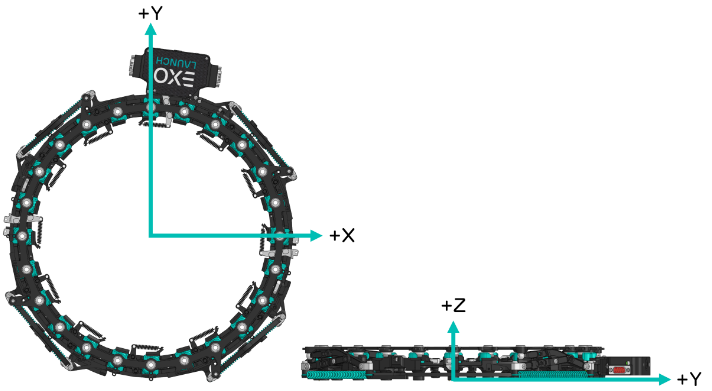
System Description

3.1 Coordinate System

The CarboNIX coordinate system is shown in the image below. The coordinate system is defined as follows:

The Z-axis is parallel to the separation direction and concentric with the mounting interface circle, with +Z pointing towards the satellite. The origin of the coordinate system is where the Z-Axis intersects the L-Ring mounting plane, offset by 1.5mm in the +Z direction. The Y-axis is defined by the first mounting point counterclockwise from the lock mechanism when viewed from the top (satellite side), with +Y pointing in the direction of the lock mechanism. The X-axis is defined by the right-hand rule.

Figure 30:
CarboNIX Coordinate System.



3.2 Mass

The mass of each CarboNIX element is listed below. Detailed mass properties can be found in Appendix A.

Table 2: CarboNIX Mass.

Description	C8	C11.732	C15	C18.25	C24
S-Ring ST [kg]	0.23	0.34	0.43	0.51	0.63
S-Ring IM [kg]	0.27	0.39	0.51	0.59	0.74
L-Ring (thru holes) [kg]	1.52	2.01	2.52	2.95	3.64
Separation Switch (incl. mounting bracket) [g]			17.3		
Separation Switch receptacle [g]			2.7		
Upper Separation Connector [g]			11.4		
Lower Separation Connector [g]			14.6		
M6x25 Socket Head Screw + NL6ss washer [g]			7.9		

3.3 Mounting Configurations

CarboNIX can be mated with the launch vehicle and the satellite in the ways shown below. For nearly any mission configuration, the "Thru Hole" variant is preferred for easier installation at the launch site. The following thread engagement is required on both the L-ring and S-ring fasteners, where D is equal to the fastener diameter:

- 1.5D for steel inserts on aluminum base metal
- 1.5D for cut threads in steel base metal
- 2.0D for cut threads in aluminum base metal

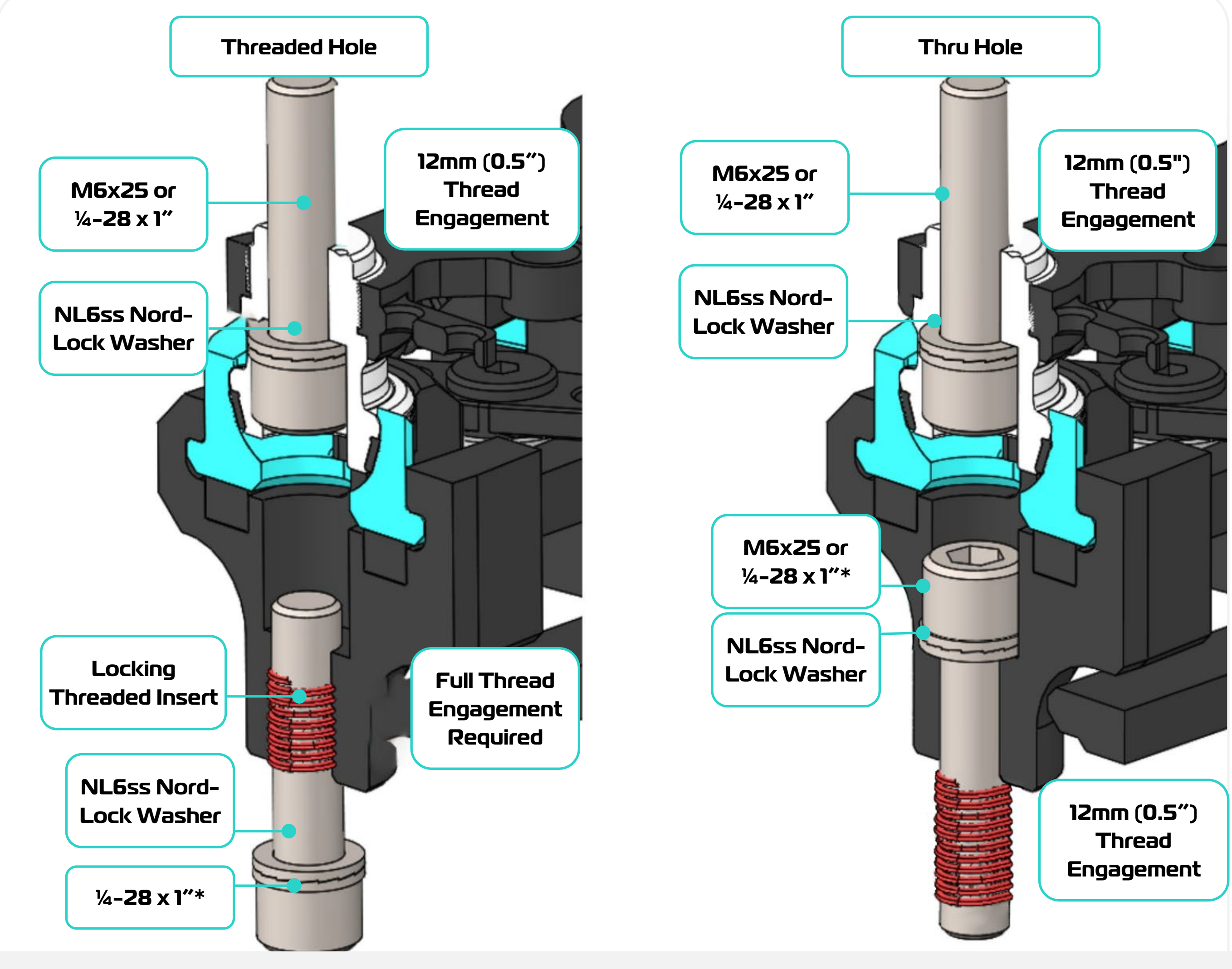


Figure 31: Launch Vehicle Mounting Configurations.

*Fastener length is dependent on the geometry of the launch-side mounting interface. Please note that only 1/4-28 threads are available in this configuration, and M6 threads cannot be added.

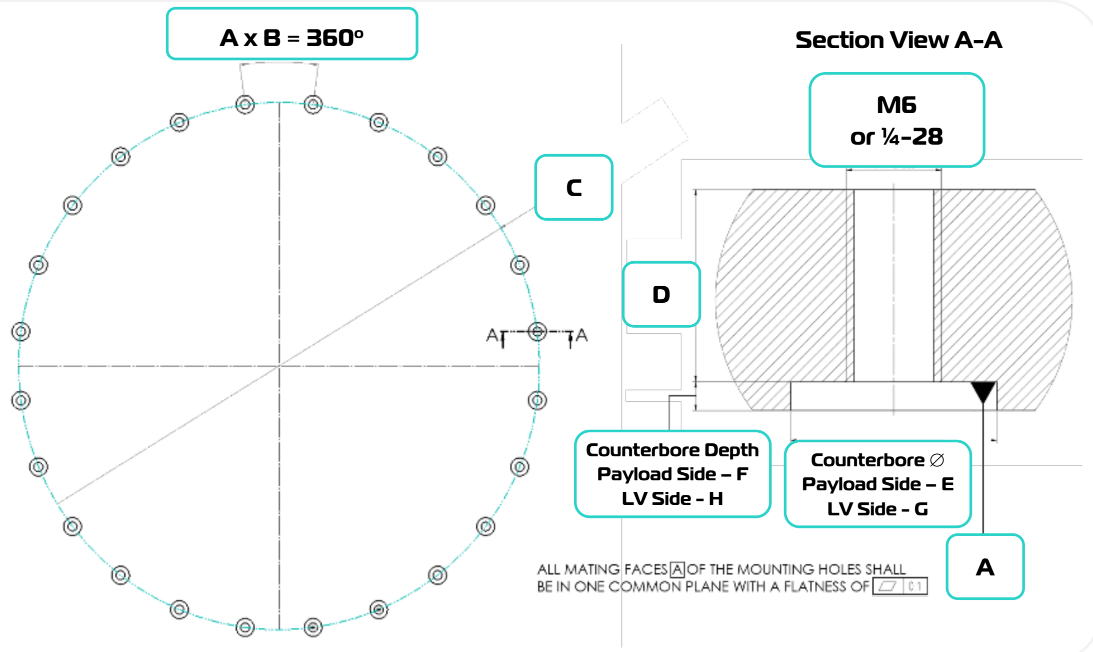
3.4 Mounting Hole Patterns

The mounting pattern for the CarboNIX system consists of a circular pattern of equally spaced holes on both the payload and launch vehicle sides. Additional counterbores are required on the payload side when using the S-Ring ST. Launch vehicle-side counterbores are not required but may be desired to increase shear load capability. For more information about interface requirements and technical drawings, see Appendix B.

Table 3: CarboNIX Interface Dimensions.

Description	Dim	Letter	C8	C11.732	C15	C18.25	C24
Number of mounting holes		A	12	18	24	28	36
Angle between mounting holes	deg	B	30	20	15	12.86	10
Mounting hole circle diameter ± 0.1	mm	C	203.2	297.99	381.0	463.55	609.6
Minimum thread engagement	mm	D	Cut threads: 12 (2.0D), Inserts: 9 (1.5D)				
S-Ring ST counterbore diameter	mm	E	13 H7				
S-Ring ST counterbore depth	mm	F	1.8				
Optional L-Ring counterbore diameter	mm	G	16.15 ± 0.05				
Optional L-Ring counterbore depth	mm	H	1.5				
Maximum chamfer size for ST and IM S-Ring	mm	-	0.5				

Figure 32: CarboNIX Mounting Pattern.



3.5 Keep-Out Dimensions

The inner and outer dimensions of the CarboNIX systems are shown below. These dimensions shall be considered the "keep-out" volume, an area where no part of the satellite or launch vehicle should protrude. In addition, protrusions shall not block access to the DSub-9 connectors and harness routing. Fit check CAD can be provided on request.

Figure 33: CarboNIX Primary Keep-Out Dimensions.

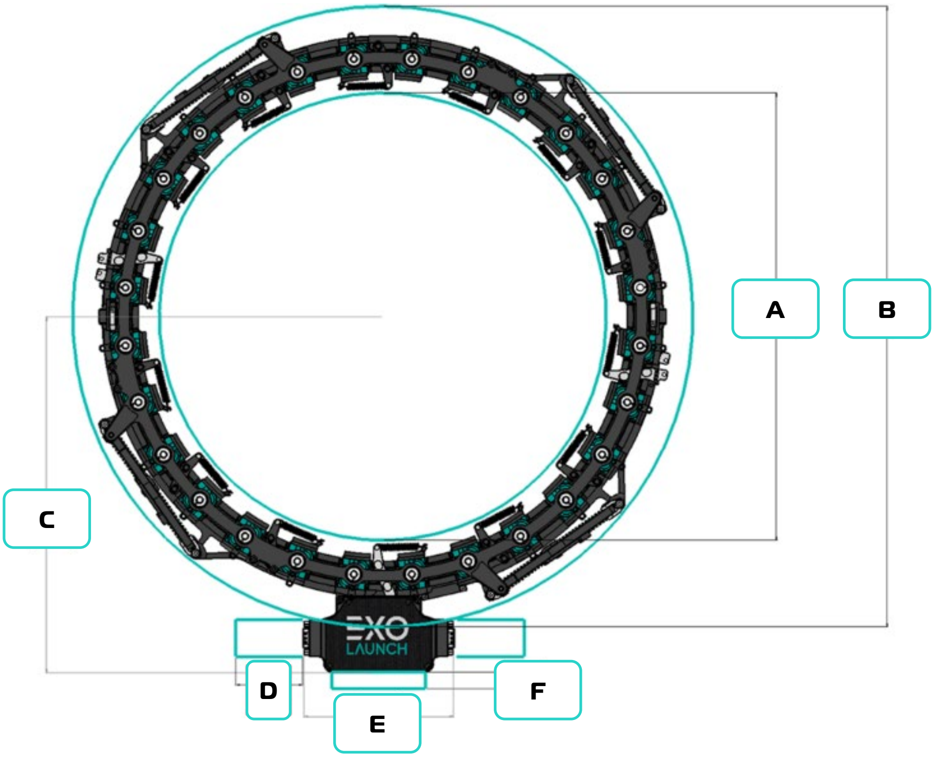


Table 4: CarboNIX Keep-out Volume.

Description	Letter	C8	C11.732	C15	C18.25	C24
Inner keep-out diameter [mm]	A	130	240	310	395	545
Outer keep-out diameter [mm]	B	300	400	475	560	700
Distance from center to lock mechanism outer edge [mm]	C	190	240	280	320	392
Deploy harness keep-out [mm]	D	60				
Lock mechanism width [mm]	E	134				
Separation indicators keep-out [mm]	F	15				
Protrusion depth from satellite base plate [mm]	-	45 (assuming solid mounting surface without additional protrusion space)				
System height [mm]	-	50.80 IM – config | 49.50 ST – config				

3.6 Maximum Loads and Stiffness

Compatibility of the satellite with CarboNIX depends on a range of factors including mass, center of gravity, satellite bus design, peaking factors and stiffness or launch vehicle requirements, and cannot be determined solely based on interface loads. However, CarboNIX is supporting the vast majority of satellites flying on SpaceX Transporter missions. Talk to Exolaunch for your mission specific analysis.

3.7 Dynamic Simulators

For satellite vibration testing, Exolaunch offers dynamic simulators for every CarboNIX size. These dynamic simulators are C-channel flanges milled from Aluminum 7075 and rated to withstand over 100 test campaigns. By tuning the stiffness properties, simulators capture the frequency of the first rocking mode of CarboNIX plus satellite to within ±10%, providing a simplified test methodology which has been approved by different launch providers including SpaceX. The suitability of a simulator, i.e. the matching of the dynamics of satellite plus CarboNIX vs satellite plus simulator, is evaluated through FE analysis and requires a representative, correlated model of the satellite. Axial dynamic response and higher-order modes are not necessarily captured with the simulator.

Dynamic simulators provide the additional benefit of offering representative mounting interfaces for CarboNIX separation switches and connectors, allowing customers to install them during the vibration campaign.

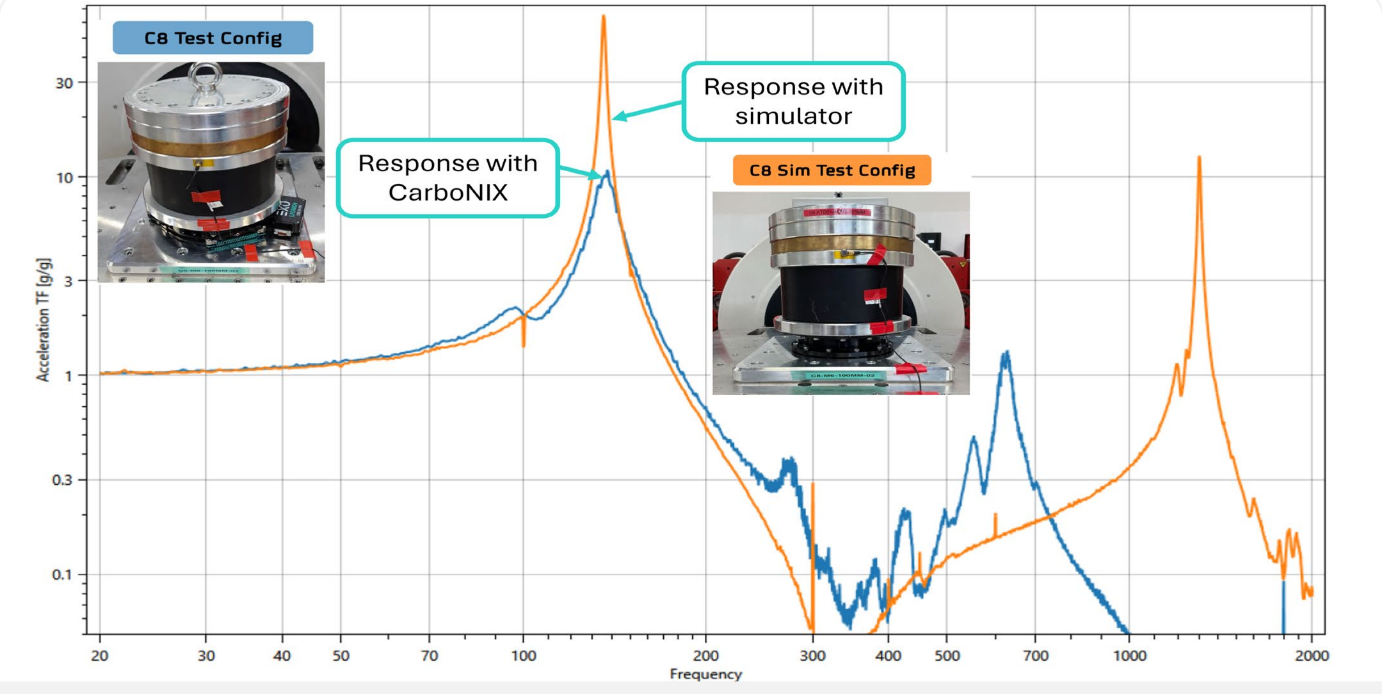


Figure 34: Dynamic Response of Satellite Dummy with CarboNIX vs. Simulator

3.8 Finite Element Modeling

For FE modeling, Exolaunch can provide detailed, Nastran based (.bdf) CarboNIX models upon request. These models are correlated to the CarboNIX dynamic behavior. The models are used for the following purposes:

- Coupled system stiffness calculations (modal, sine, random vibe analyses)
- Assessment of the segment loads at the CBUSH elements per section 3.6

The models are NOT representative in terms of strength or thermo-elastic properties of the CarboNIX.

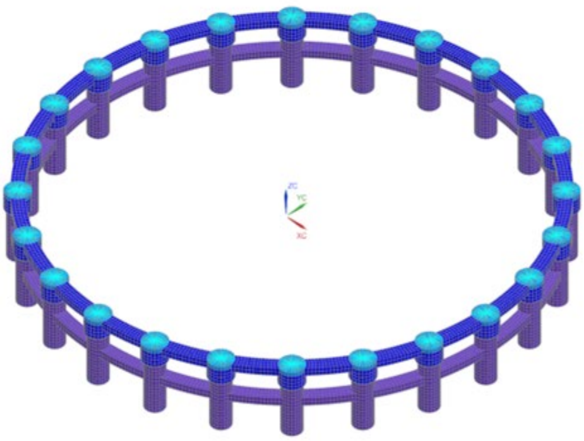
3.8.1 FEM Description and Guidelines

The FE model comprises the following components:

- S-ring – The ring attachment to the satellite
- L-ring – The ring attachment to the launcher side
- CBUSH elements – Tuned springs representing the locking segments' stiffness

All models use SI units and all data from NASTRAN result files refer to meters, kilograms, Newtons and seconds. The CarboNIX to Launch Vehicle interface bolts shall be connected via an RBE2 element with an independent grid at the geometrical center of the circular interface. All load cases and boundary conditions shall be applied on the single-interface RBE2 node.

Figure 35:
CarboNIX 15" FEM



CarboNIX provides two sets of interface nodes:

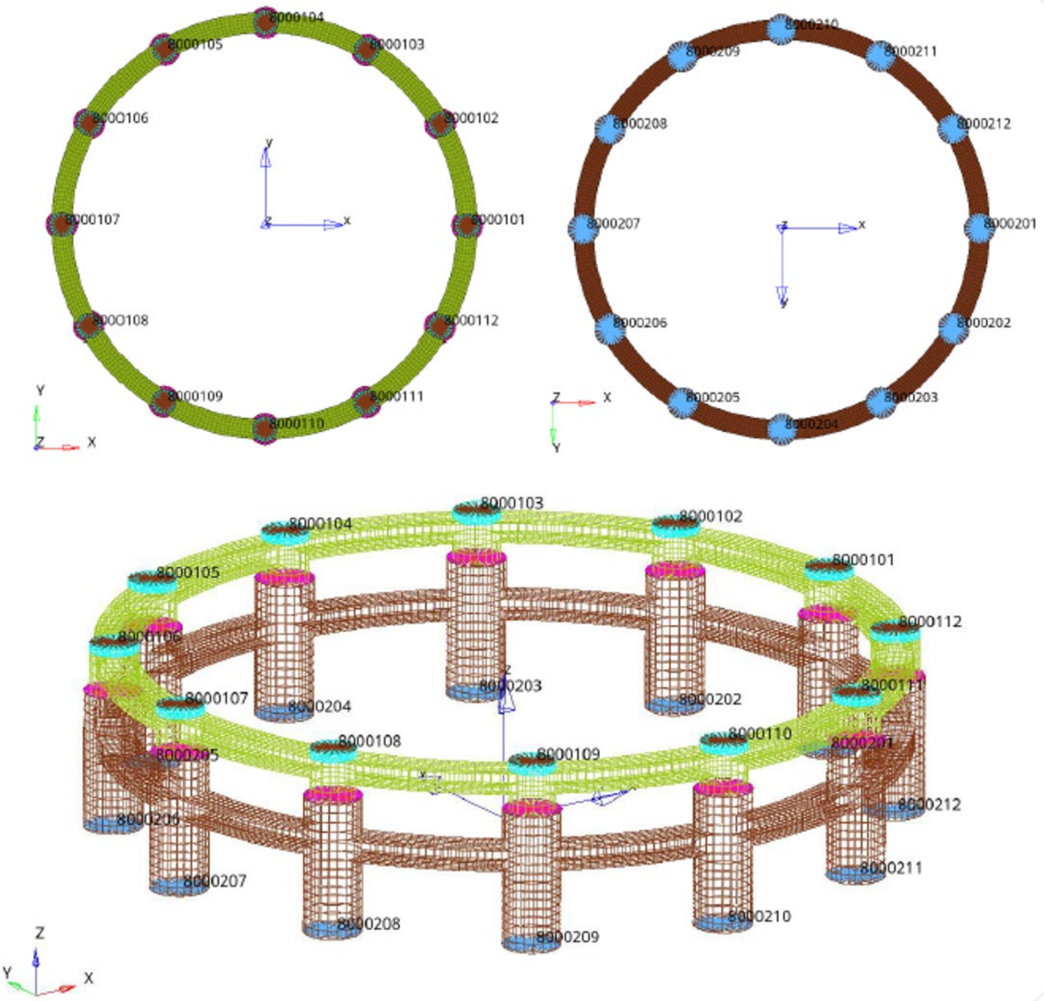
- To the satellite (S-side): 8000101 – 80001**X**
- To the launcher (L-side): 8000201 – 80002**X**

Where X is the number of interface nodes. All interface nodes are defined in cylindrical coordinate system 8000002.

Table 5: CarboNIX FEM Coordinate System definition.

Coord Sys ID	Nastran Card	Reference Coord Sys ID	Description
8000001	CORD2R	0	Main CarboNIX Coordinate System
8000002	CORD2C	8000001	Cylindrical Coordinate System

Figure 36:
Interface nodes of the CarboNIX 8" FEM.



3.9 Minimum Stiffness Requirements

In order to guarantee the functioning of the system, both the satellite and launch vehicle must be stiff enough that any deformation of the CarboNIX occurs entirely within the elastic range, and thus returns to its original geometry after unloading. If the following requirements are not met, the reliable functioning of the system cannot be guaranteed.

- All mounting surfaces of both the S-Ring and the L-Ring shall be mounted on a common plane that maintains a flatness tolerance of 1 mm under load.
- Two adjacent mounting surfaces shall be mounted on a common plane that maintains a flatness tolerance of 0.085 mm under load.

3.10 Separation Velocity

Separation velocity depends on the spacecraft mass and the strength of the separation springs. The spring strength can be tailored to match a desired deployment velocity by mixing and matching from the available spring strengths. Using springs of different strengths has no effect on the tip-off rate. Figure 37 demonstrates the relationship between satellite mass and deployment speed relative to different values of the total spring energy.

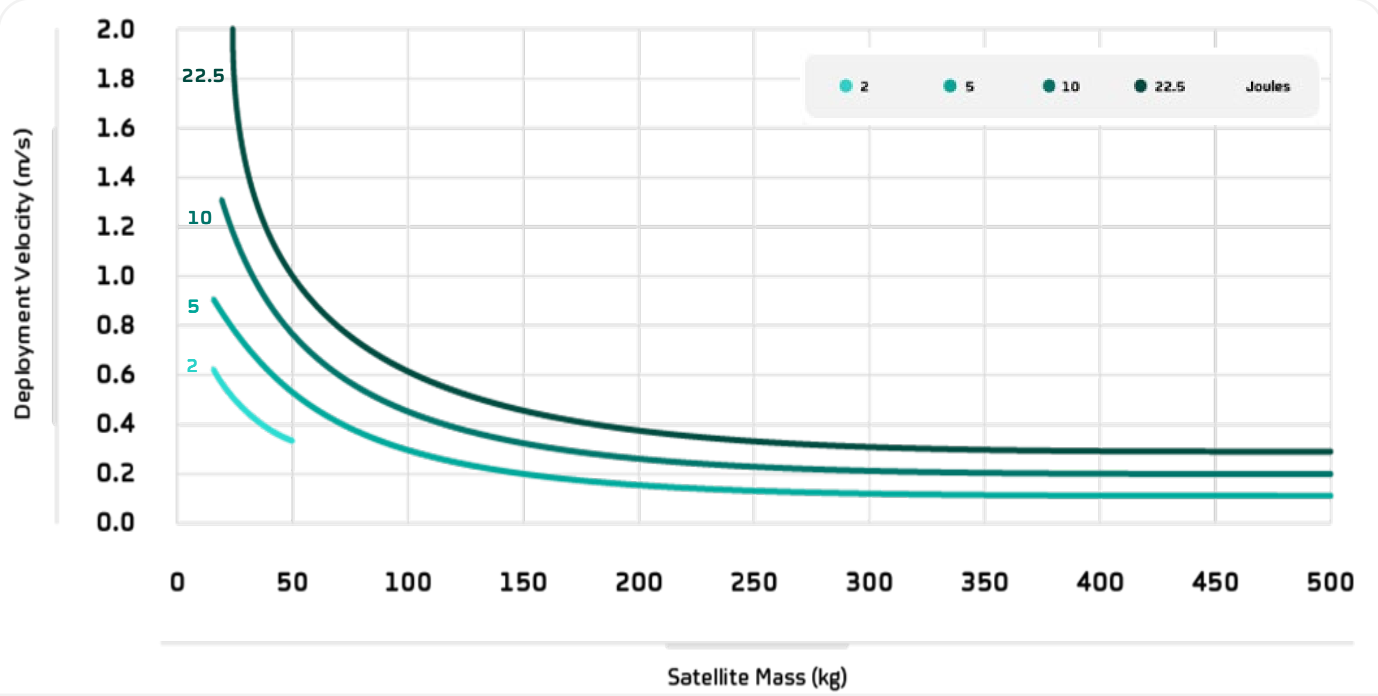


Figure 37: Deployment Velocity vs. Satellite Mass.

The spring sets have a total energy tolerance of about 20%. Precise spring strengths will be measured in the course of the mission, increasing the precision to 2%. Table shows the minimum and maximum values of the separation energy. For separation velocity calculations, the equation for Kinetic Energy can be used.

$$KE = \frac{1}{2}mv^2$$

Table 6: Spring Set to Minimum and Maximum Energy.

Description	C8	C11.732	C15	C18.25	C24
Number of springs	3	3	4	4	6
Spring 1 energy (brown) [J]	0.7	1.1			
Spring 2 energy (black) [J]	1.3	2.2			
Spring 3 energy (green) [J]	2.25	3.7			

3.11 Tip-Off Rates

Due to the unique design of the CarboNIX pusher arm system, all four pusher arms will extend at the same speed, regardless of the loads each individual arm faces. For this reason, the satellite will separate with near-zero initial rotation, regardless of the satellite mass distribution.

Results from satellites deployed in space show an average rotation rate of 0.6 deg/s across all three axes. No axis rotation higher than 2 deg/s has been recorded from satellites deployed by CarboNIX.

Table 7: Examples of customer-reported tip-off rates for different satellites types.

No.	Satellite Mass [kg]	CG RSS Eccentricity [mm]	Spring Energy (J)	Deploy Velocity [m/s]	CarboNIX Tip-Off Rate [deg/s]			
					X	Y	Z	ABS MAX
1	110	5	4.4	0.28	-0.40	1.09	-0.54	**1.09**
2	110	5	15.5	0.53	0.13	0.34	0.04	**0.34**
3	110	5	9.4	0.41	0.25	0.40	1.90	**1.9**
4	99.7	11	15.5	0.56	0.28	-0.59	0.97	**0.97**
5	104.4	26.7	15.5	0.54	0.12	1.97	0.65	**1.97**
6	89.6	28	9.4	0.46	-0.60	-1.01	0.98	**1.01**
7	116.7	16.1	15.5	0.52	0.97	0.12	2.20	**2.2**
8	90.9	24.1	15.5	0.58	1.47	0.61	-0.77	**1.47**
9	91.7	36.1	9.4	0.45	-0.59	-0.41	-0.37	**0.59**
10	90.8	28	15.5	0.58	1.02	-0.83	0.51	**1.02**
11	89.9	35.7	15.5	0.59	0.27	0.03	0.79	**0.79**
12	108.8	15.7	15.5	0.53	0.05	1.39	1.34	**1.39**
13	110	5	4.4	0.28	0.50	0.50	0.90	**0.9**
14	89.6	28	10.4	0.48	-0.70	-0.49	0.80	**0.8**
15	105	26.7	15.5	0.54	0.02	1.80	2.22	**2.22**
16	91.4	34.3	15.5	0.58	1.45	0.25	-0.23	**1.45**
17	110	5	15.5	0.53	-0.29	-0.10	-0.26	**0.29**
18	110	5	9.4	0.41	-0.31	-0.28	-0.78	**0.78**
19	90.4	22.7	15.5	0.59	-0.80	-0.25	0.13	**0.8**
20	88.7	13.7	9.4	0.46	0.03	0.70	0.54	**0.7**
21	89.3	28	13.9	0.56	0.48	0.49	0.61	**0.61**
22	96.1	12.8	13.9	0.54	-0.80	0.59	1.89	**1.89**
23	21.9	6.6	4.4	0.63	1.38	0.73	1.21	**1.38**
							Max tip-off rate (deg/s)	**2.22**

3.12 Separation Shock

Shock values generated by CarboNIX during release are very low. However, some shock is still generated during separation due to the sudden release of spring energy. Separation shock values were determined during multiple CarboNIX qualification campaigns.

Figure 38:
Shock Sensors Measure Shock Generated by CarboNIX during the Separation.

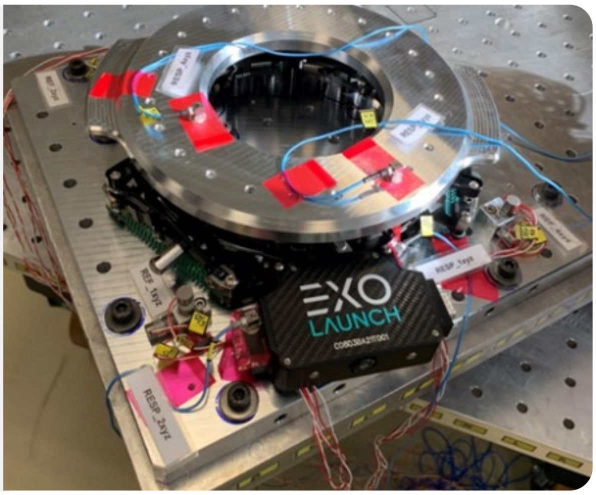
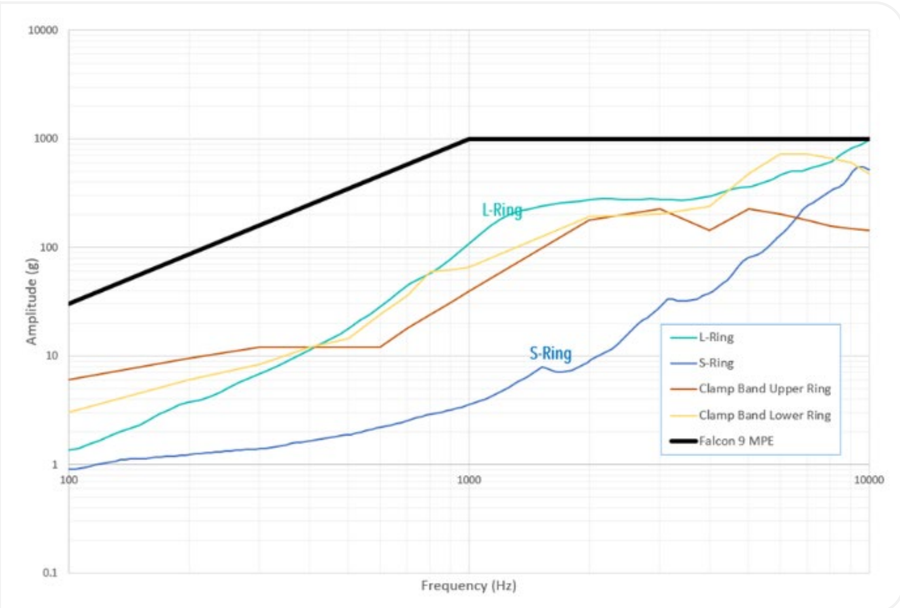


Figure 39:
CarboNIX 15
Shock Response Spectrum.



As shown in Figure 39 the CarboNIX L-Ring generates comparable shock loads to the lower rings of same-sized clamp band systems. This may be important to consider in a mission scenario where multiple CarboNIX units are placed in close proximity to each other. When just a single unit is considered, the shock loads generated by CarboNIX which reach the payload are lower than clamp band systems by up to a factor of 10 across the majority of the frequency spectrum.

3.13 Electrical Interfaces

3.13.1 DSub-9 Connectors

The CarboNIX locking mechanism has two male DSub-9 connectors (Harting 09674095615). The connectors are fully redundant and either one or both connectors can be used to trigger CarboNIX.

Figure 40: Illustration of the Two DSub-9 Connectors.

Table 8: CarboNIX Pinout.

Pin	Designation	Function	Continuity Check Across Pins
1	Clamp Ring TM1	Closed after deployment	
2	Pusher Arm TM2	Closed after deployment	
3	-	-	
4	Actuator 2	Return	1.2V ± 5% drop across pins, using multimeter* in Diode mode.
5	Actuator 2	VCC	
6	Clamp Ring TM1	Closed after deployment	
7	Pusher Arm TM2	Closed after deployment	
8	Actuator 1	Return	1.2V ± 10% drop across pins, using multimeter* in Diode mode.
9	Actuator 1	VCC	

*Explosion-safe multimeter not required.

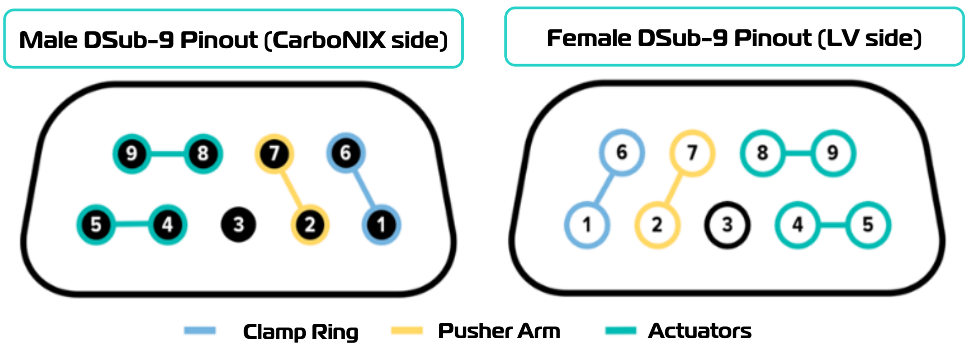


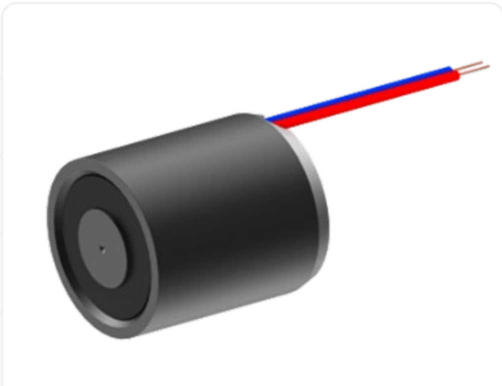
Figure 41: CarboNIX Pinout schematics.

3.13.2 Separation Signal

CarboNIX uses two permanent electromagnets at the heart of the locking mechanism. Similar to a solenoid, these devices use a permanent magnet to hold CarboNIX locked in place, without power, until the separation signal is received.

Table 9: Permanent Electromagnet Properties and example of permanent magnet.

Holding force [N]	70	Minimum All-fire Current [mA]	160
Voltage Drop	1.2V ± 10%	Nominal Separation Current [mA]	280
Nominal Voltage [V]	28	Maximum Current [mA]	500
Voltage Range [V]	24-36	Nominal Pulse Duration [ms]	500
Maximum No-fire Current [mA]	25	Duty Cycle (cycle time 30s)	10%



3.13.3 Grounding

CarboNIX provides an electrically conductive path from the satellite interface to the launch vehicle. The satellite manufacturer is responsible for ensuring that the M6 or 1/4" threads at the mounting interface are electrically connected to the rest of the satellite structure.

3.14 Thermal Properties

For thermal modeling exercises, the following measured thermal properties of the CarboNIX system can be used.

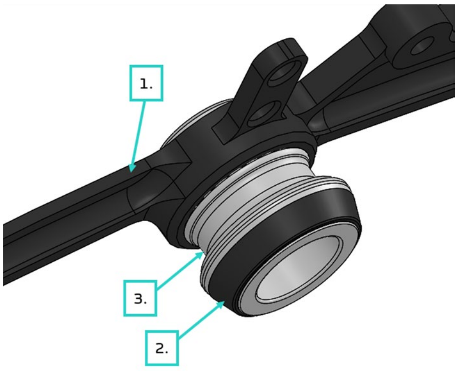


Figure 42: S-Ring thermal elements.

Table 10: CarboNIX S-Ring Thermal Properties.

No.	Color	Emissivity	Absorptivity
1	Black	0.89	0.72
2	Black	0.87	0.92
3	Dark Grey	0.54	0.86

4

Installation and Operation

4.1 Installation

This chapter describes the procedures for the installation of the CarboNIX with the launch vehicle and satellite, as well as the proper process for installing accessories.

4.1.1 Separation Switch Installation

If the customer chooses to use the separation switch, it will be delivered earlier than the full CarboNIX unit to provide sufficient time to integrate it with the satellite harnessing.

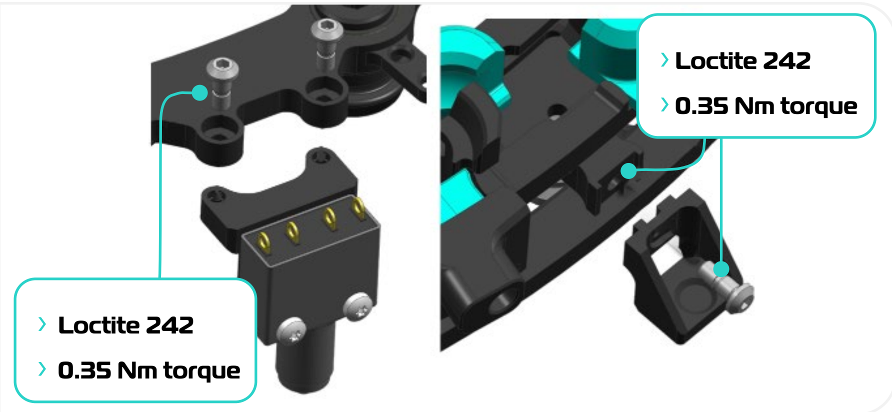


Figure 43:
Separation Switch Mounting Assembly.

The separation switch is mounted to the S-Ring using custom M3 fitted screws. The lower plunger receptacle uses the same screw. Both should be locked in place using Loctite 242. For the plunger receptacle mounting hole, Loctite 242 must be used both on the screw threads and the hole. Screws shall be torqued to 0.35 Nm.

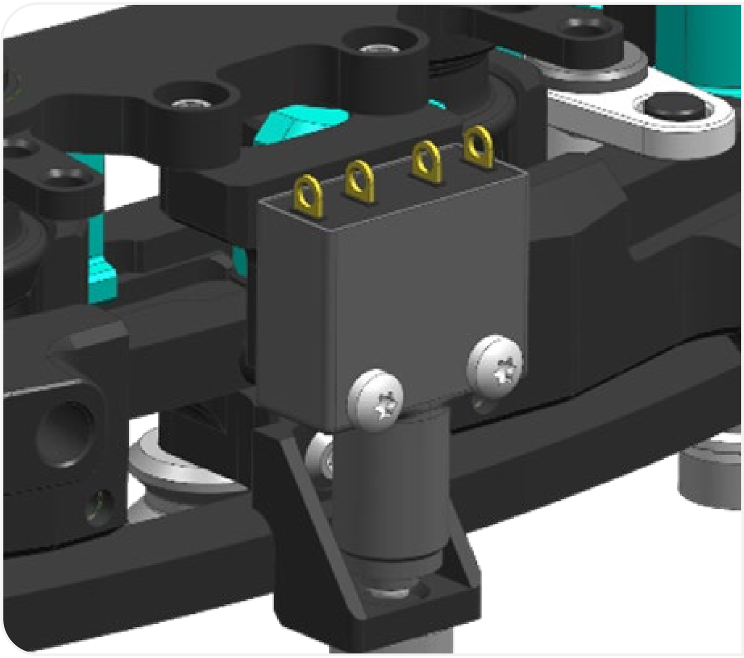


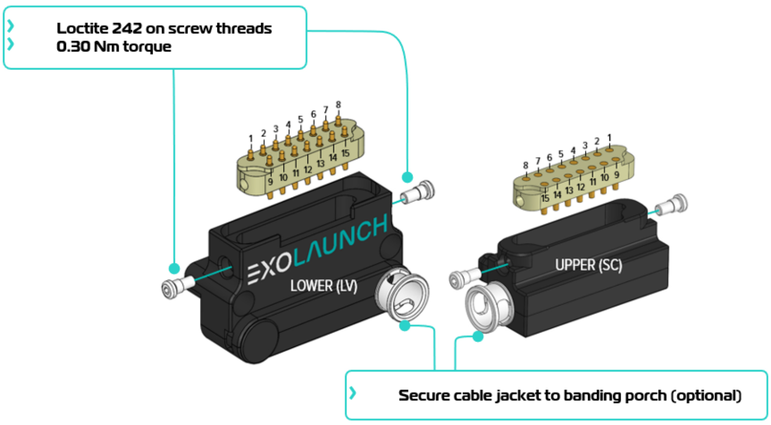
Figure 44:
Assembled Separation Switch.

4.1.2 Separation Connector Installation

The separation connector can be used to provide an electrical connection to the satellite after it has been integrated on the launch vehicle. It can be used to charge the satellite batteries or even to communicate the separation event.

Each connector half has 15 pins with solder cup connections. Maximum wire size is 19 AWG; smaller wire sizes may be required when a large number of pins are populated.

Figure 45:
Separation Connector Assembly.



4.1.3 Installing S-Ring and L-Ring

The S-Ring and L-Ring are mounted using the same fasteners and the same techniques.

1. Double check the orientation to ensure clocking is correct (See section 2.3.6).
2. Insert all screws (DIN 912 M6x25 BUMAX-109 or NAS1351N4-16) with NL6ss Nord-Lock washers. For customers flying with the ST ring, A4-80 fasteners are suitable. Note that fastener length can vary on the L-Ring side, depending on the mounting interface.
   CAUTION: The L-Ring pusher arms must be extended during installation of the L-Ring to avoid putting the ring under tension during the process
3. Tighten all screws in a double cross pattern and then circular, as can be seen in Figure 46.
   CAUTION: Do not tighten clockwise first without the double cross pattern, as this could lead to uneven loading of the S-Ring or L-Ring.
   - Tighten all screws to (1/3 * X) Nm.
   - Tighten all screws to (2/3 * X) Nm.
   - Tighten all screws to X ± 0.5 Nm.

Torque X is based on the required fastener preload, which depends on the selected S-Ring configuration. Since preload is based on the threaded hole and fastener type and may vary significantly, it is required that the customer verify to Exolaunch that the minimum fastener preload is achieved.

Table 11: Fastener Torques and Preload.

S-Ring Type	Nominal Fastener Preload	Recommended fastener preload for M6 threads (X)*
Standard	8.5 kN	10.0 Nm
IM	11 kN	12.5 Nm

*Caution: **This torque calculation is valid only for M6 screws without thread lubricant. The customer is required to recalculate the necessary torque and show that the nominal fastener preload is achieved!**

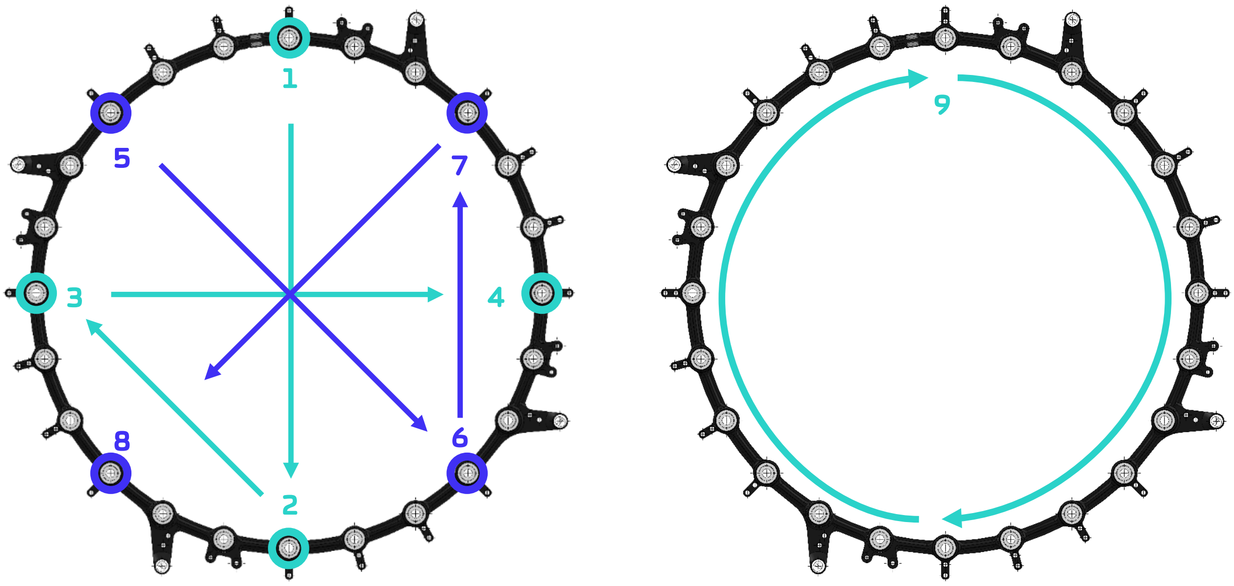


Figure 46: Torque pattern for one torque level on the S-Ring (Identical pattern on the L-Ring).

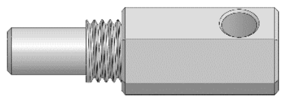
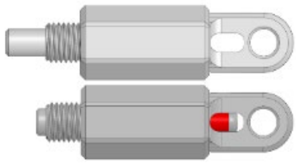
4.2 Operation

The CarboNIX unit can be mounted on the satellite and launch vehicle in several ways. Rather than describing every single possible integration sequence or mounting orientation, this section will describe the required steps for safe and successful integration. Detailed integration procedures shall be confirmed by Exolaunch on a case-by-case basis.

4.2.1 Tools and Equipment

The CarboNIX is delivered with the following items as standard.

Table 12: Tools and equipment included with delivery and required to operate, store and transport CarboNIX.

Tool	Description	QTY	Picture
Angled Circlip Pliers Knipex 44 21 J31	Primary pliers for engaging clamp rings	2*	
Pusher Arm RBF	Used to lock the pusher arms in the down position	4 (3 in case of CarboNIX 8)	
Clamp Ring RBF	Spring-loaded RBF pin. Red indicator is visible when clamp rings are not locked	2 (1 in case of CarboNIX 8)	
Pelican Travel Case	Packed with custom laser-cut foam for transporting CarboNIX unit plus tools and fasteners	1	

***If multiple CarboNIX units are ordered, only one set of tools will accompany the delivery.**

All tools and equipment shall be returned to Exolaunch at the completion of the mission.
Customers are responsible for providing their own fasteners and confirming compatibility with Exolaunch!

4.2.2 Status at Delivery

CarboNIX shall be stored and delivered in a low-energy state, with all springs in their relaxed position. Specifically, this means that:

- The pusher arms are extended.
- The clamp rings are not engaged.
- The release mechanism is not armed.
- The S-Ring is not connected to the L-Ring.

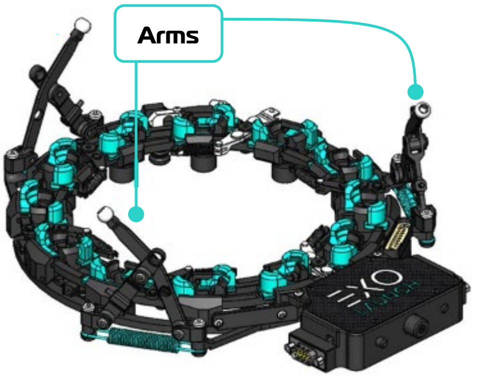
When storing CarboNIX for longer periods of time, it should always be returned to this state.

4.2.3 Locking the Pusher Arms

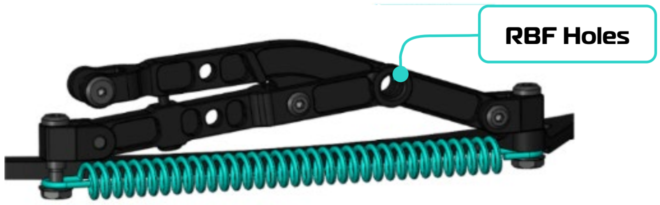
The pusher arms can be optionally locked in the down position during integration using RBF pins. The satellite and S-ring may also be mated with the L-Ring with the arms in the extended configuration. This step shall be performed by **two people.**

CAUTION: An uncontrolled release of the pusher arms will cause **SEVERE AND IRREPARABLE DAMAGE** to the system.

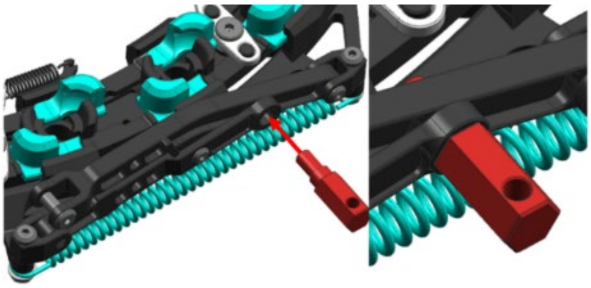
With the CarboNIX unit resting on a stable surface, carefully push down on two opposite arm pairs to lower the arms to the stowed position.



Push down on the arms until the RBF holes are aligned.



A second person shall insert the RBF pins into the arm/s that are not being held down. Turn the RBF pins until they are fully inserted.



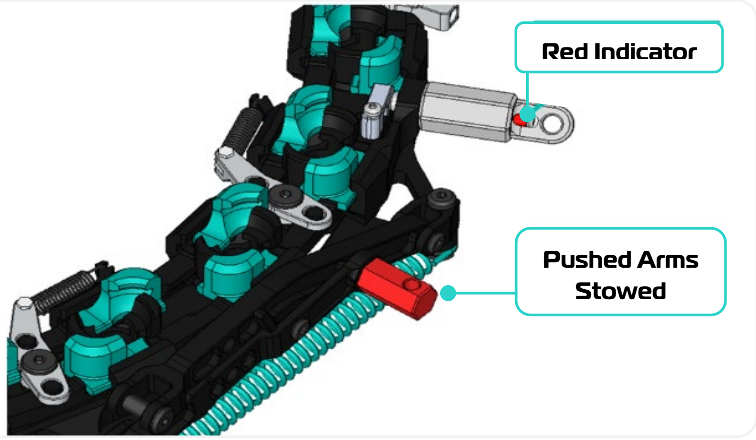
Insert the remaining RBF pins. Turn the RBF pins until they are fully inserted.

4.2.4 Locking S-Ring to L-Ring

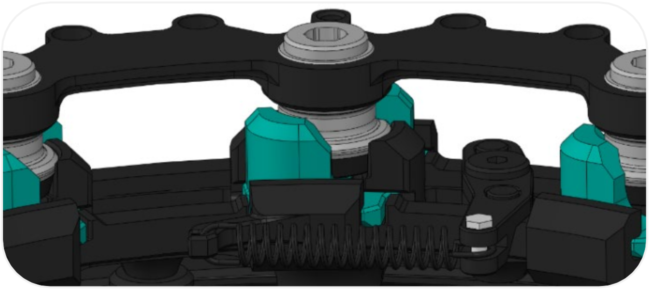
In order to lock the S-Ring together with the L-Ring, the mechanisms must be in the following state:

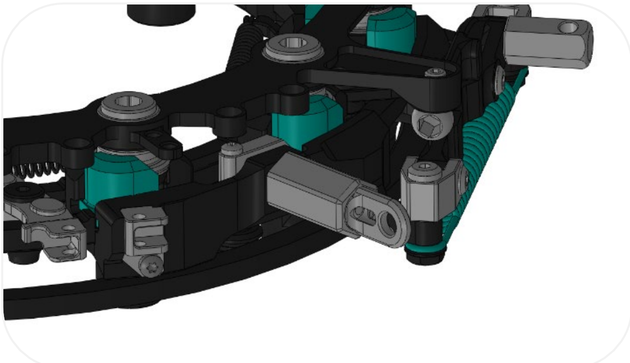
- The S-Ring is installed on the satellite base plate. See Section 4.1.3 for details.
- The clamp rings are open and not engaged. The clamp ring RBF pins are installed, and the red indicator is visible.
- The lock mechanism is disengaged.
- [Optional] The pusher arms are secured with RBF pins. Note that in most cases, extended pusher arms are advantageous and recommended, as they allow easy and precise positioning of the S-Ring above the L-Ring prior to touch down.
- All required separation switches and separation connector components are installed.

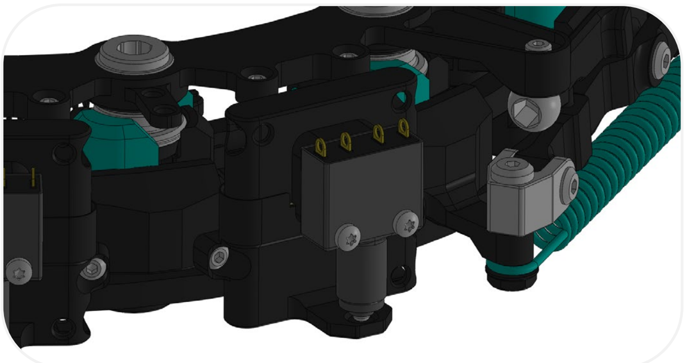
Figure 47:
L-Ring State when Locking to the S-Ring.



1. Place the S-Ring onto the L-Ring so that the domes of the S-Ring are resting on the L-Ring. **CORRECT ORIENTATION** is achieved when the pusher arms rest in their S-Ring receptacle and when the switches and connectors are aligned.
2. Use the pliers to engage the clamp rings. The clamps are fully engaged only when the red indicators on both RBF pins disappear.



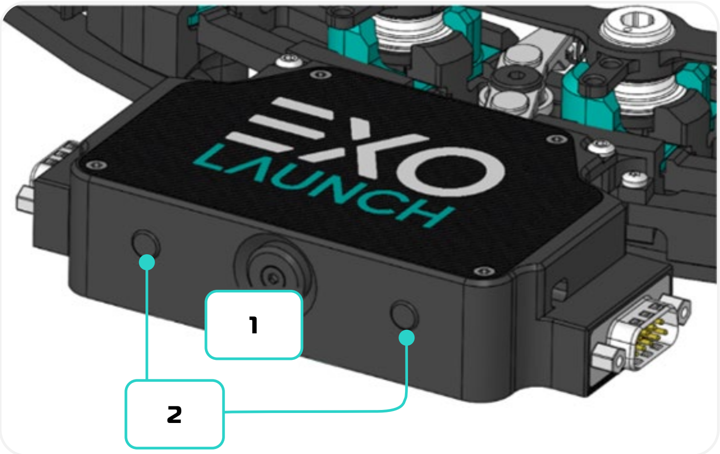




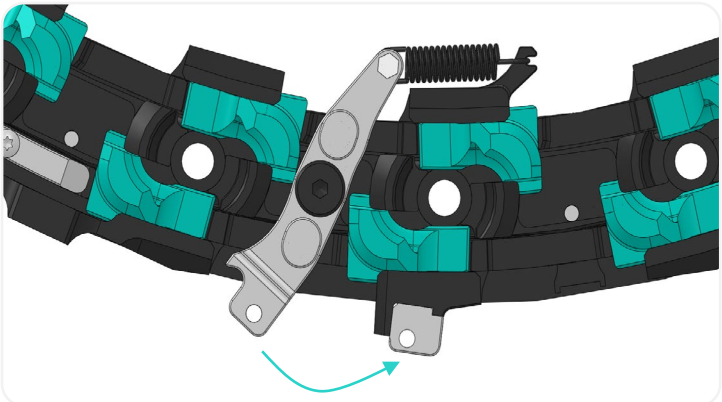
4.2.5 Engaging the Lock Mechanism

The lock mechanism can only be engaged when the clamp rings are locked in the closed position with RBF pins inserted (see 4.2.4).

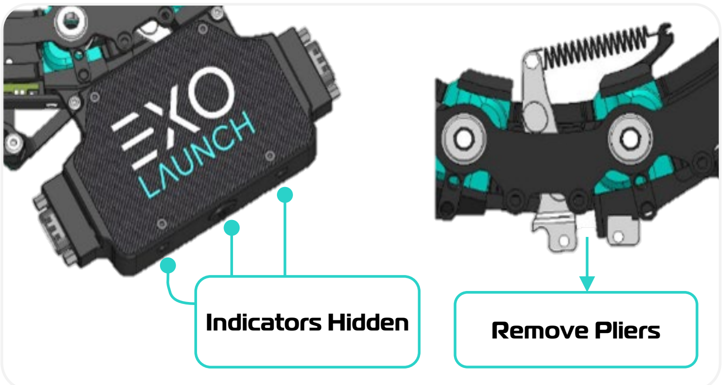
1. To engage the release mechanism, all three indicators must be pushed fully within the housing.
   The locks are engaged by pushing and holding the inhibit pin (1), then the two lock indicators (2), before letting go of the inhibit pin.



2. Install the spring-loaded clamp ring RBFs (see Section 4.2.4) and use the pliers to engage the clamp rings. When the red indicators on the RBF disappear, the lock mechanism is ready to engage. In some cases, applying additional force to the pliers (gently) will reduce the force required to close the release mechanism.



3. When the release mechanism is properly engaged, it will remain closed.
4. If both magnets hold, then the system is secure, and the pliers and RBF elements can be removed.



4.2.6 Functional Tests

A functional test shall be performed to confirm the proper functioning of the release mechanism. It should also be done at the launch site to confirm that the firing signals from the upper stage are properly triggering a release.

CAUTION: The CarboNIX system must be secured with at least one clamp ring RBF pin before this test is performed. Failure to do so may cause **SEVERE AND IRREPARABLE DAMAGE** to both the CarboNIX unit and to the customer satellite.

Securing the locks shall be performed in accordance with the instructions in 4.2.5.

1. Ensure at least one clamp ring RBF pin is properly installed and the red indicator on the RBF pin is not visible.
2. Check that both lock indicators are closed.
3. Open Lock 1. Check that the indicator is visible.
4. Secure Lock 1.
5. Open Lock 2. Check that the indicator is visible.
6. Secure Lock 2.

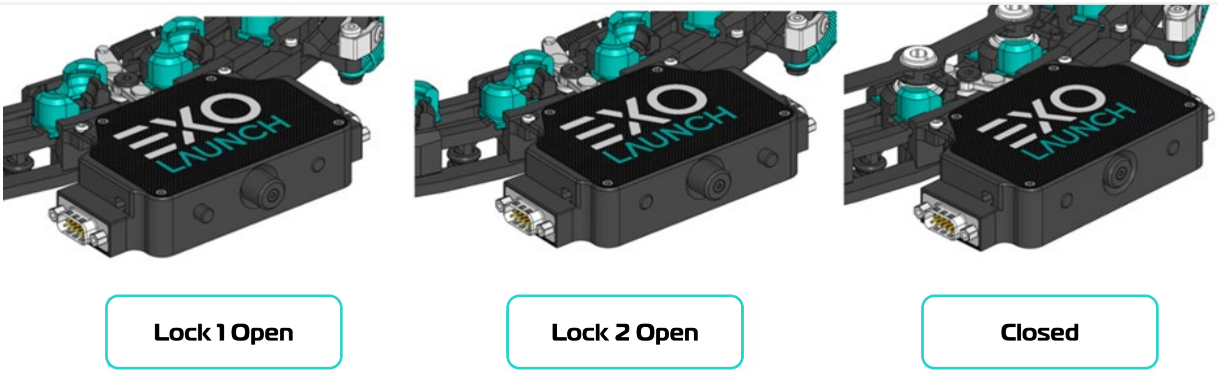


Figure 48: Functional Testing Configurations.

4.2.7 Harness Continuity Check

The CarboNIX lock mechanism features a diode bridge rectifier serving as a reserve polarity protection feature. To measure continuity, the multimeter must be set to diode mode. A 1.2V +/-10% voltage drop is expected across each actuator pin pair, see Table 8.

A

Appendix

Detailed Mass Properties

CarboNIX 8

Table 13: CarboNIX 8" Mass Properties

L-Ring Mass [kg]			1.52	
S-Ring Type			ST	IM
S-Ring Mass [kg]			0.23	0.27
L-Ring Stowed	Center of Gravity [mm]	X	8.60	
		Y	31.38	
		Z	19.63	
	Moment of Inertia [kgmm²]	X	12998.67	
		Y	8162.27	
		Z	20947.58	
	Product of Inertia [kgmm²]	YZ	2.93	
		XZ	-11.06	
		XY	1796.74	
L-Ring Deployed	Center of Gravity [mm]	X	8.67	
		Y	31.50	
		Z	21.02	
	Moment of Inertia [kgmm²]	X	13215.25	
		Y	8368.56	
		Z	21113.55	
	Product of Inertia [kgmm²]	YZ	-63.37	
		XZ	-29.31	
		XY	1814.39	
S-Ring	Center of Gravity [mm]	X	0.00	0.00
		Y	0.00	0.00
		Z	40.02	40.94
	Moment of Inertia [kgmm²]	X	1295.51	1468.17
		Y	1295.51	1468.16
		Z	2578.08	2920.09
	Product of Inertia [kgmm²]	YZ	0.00	0.00
		XZ	0.00	0.00
		XY	0.00	0.00
Combined System Stowed	Center of Gravity [mm]	X	7.46	7.32
		Y	27.21	26.71
		Z	22.33	22.80
	Moment of Inertia [kgmm²]	X	14576.39	14792.20
		Y	9556.48	9749.65
		Z	23738.97	24106.95
	Product of Inertia [kgmm²]	YZ	-126.01	-148.22
		XZ	-46.40	-52.48
		XY	1851.12	1857.59

CarboNIX 11.732

Table 14: CarboNIX 11.732" Mass Properties

L-Ring Mass [kg]			2.01	
S-Ring Type			ST	IM
S-Ring Mass [kg]			0.34	0.39
L-Ring Stowed	Center of Gravity [mm]	X	5.36	
		Y	31.01	
		Z	19.55	
	Moment of Inertia [kgmm²]	X	31246.80	
		Y	21281.32	
		Z	52231.31	
	Product of Inertia [kgmm²]	YZ	3.40	
		XZ	-7.61	
		XY	2176.70	
L-Ring Deployed	Center of Gravity [mm]	X	5.40	
		Y	31.09	
		Z	21.47	
	Moment of Inertia [kgmm²]	X	31757.37	
		Y	21757.46	
		Z	52603.74	
	Product of Inertia [kgmm²]	YZ	-116.38	
		XZ	-28.46	
		XY	2197.76	
S-Ring	Center of Gravity [mm]	X	0.63	0.55
		Y	-1.39	-0.15
		Z	39.93	40.95
	Moment of Inertia [kgmm²]	X	3847.33	4489.23
		Y	3927.82	4509.17
		Z	7755.98	8974.04
	Product of Inertia [kgmm²]	YZ	-1.89	0.23
		XZ	0.82	0.62
		XY	-51.87	-31.79
Combined System Stowed	Center of Gravity [mm]	X	4.69	4.58
		Y	26.39	25.96
		Z	22.46	23.02
	Moment of Inertia [kgmm²]	X	35514.44	36202.10
		Y	25334.71	25947.42
		Z	60294.86	61529.56
	Product of Inertia [kgmm²]	YZ	-187.93	-213.88
		XZ	-34.43	-40.53
		XY	2168.77	2193.75

CarboNIX 15

Table 15: CarboNIX 15" Mass Properties

L-Ring Mass [kg]			2.52	
S-Ring Type			ST	IM
S-Ring Mass [kg]			0.43	0.51
L-Ring Stowed	Center of Gravity [mm]	X	4.78	
		Y	31.43	
		Z	19.66	
	Moment of Inertia [kgmm²]	X	58437.67	
		Y	44054.97	
		Z	102110.85	
	Product of Inertia [kgmm²]	YZ	20.70	
		XZ	2.79	
		XY	2027.74	
L-Ring Deployed	Center of Gravity [mm]	X	4.83	
		Y	31.50	
		Z	21.70	
	Moment of Inertia [kgmm²]	X	59113.27	
		Y	44650.52	
		Z	102566.51	
	Product of Inertia [kgmm²]	YZ	-141.36	
		XZ	-21.74	
		XY	2038.71	
S-Ring	Center of Gravity [mm]	X	0.03	0.06
		Y	0.22	0.46
		Z	39.82	40.86
	Moment of Inertia [kgmm²]	X	8130.74	9464.45
		Y	8112.93	9421.61
		Z	16218.60	18853.97
	Product of Inertia [kgmm²]	YZ	0.31	0.51
		XZ	0.04	0.07
		XY	2.48	5.74
Combined System Stowed	Center of Gravity [mm]	X	4.08	3.99
		Y	26.84	26.25
		Z	22.62	23.21
	Moment of Inertia [kgmm²]	X	67079.88	68496.40
		Y	52326.81	53675.63
		Z	118698.76	121378.87
	Product of Inertia [kgmm²]	YZ	-212.08	-255.81
		XZ	-32.65	-39.37
		XY	2085.16	2095.16

CarboNIX 18.25

Table 16: CarboNIX 18.25" Mass Properties

			ST	IM
L-Ring Mass [kg]			2.95	
S-Ring Type			ST	IM
S-Ring Mass [kg]			0.51	0.59
L-Ring Stowed	Center of Gravity [mm]	X	3.83	
		Y	31.67	
		Z	19.46	
	Moment of Inertia [kgmm²]	X	95804.62	
		Y	75490.30	
		Z	170856.98	
	Product of Inertia [kgmm²]	YZ	41.44	
		XZ	5.99	
		XY	2360.75	
L-Ring Deployed	Center of Gravity [mm]	X	3.87	
		Y	31.74	
		Z	21.20	
	Moment of Inertia [kgmm²]	X	96481.70	
		Y	76077.64	
		Z	171298.60	
	Product of Inertia [kgmm²]	YZ	-121.72	
		XZ	-13.60	
		XY	2371.15	
S-Ring	Center of Gravity [mm]	X	0.02	0.05
		Y	-0.09	0.48
		Z	39.85	40.88
	Moment of Inertia [kgmm²]	X	13915.40	16172.33
		Y	13925.71	16108.24
		Z	27811.68	32243.05
	Product of Inertia [kgmm²]	YZ	-0.19	0.61
		XZ	0.05	0.07
		XY	2.96	7.32
Combined System Stowed	Center of Gravity [mm]	X	3.27	3.20
		Y	27.01	26.48
		Z	22.45	23.02
	Moment of Inertia [kgmm²]	X	110336.53	112680.50
		Y	89602.22	91831.09
		Z	199111.51	203585.06
	Product of Inertia [kgmm2]	YZ	-239.03	-286.29
		XZ	-27.57	-33.72
		XY	0.02	0.05

CarboNIX 24

Table 17: CarboNIX 24" Mass Properties

L-Ring Mass [kg]			3.64	
S-Ring Type			**ST**	**IM**
S-Ring Mass [kg]			0.63	0.74
L-Ring Stowed	**Center of Gravity [mm]**	**X**	3.05	
		Y	32.37	
		Z	19.37	
	Moment of Inertia [kgmm²]	**X**	192276.85	
		Y	162824.67	
		Z	354559.63	
	Product of Inertia [kgmm²]	**YZ**	60.80	
		XZ	6.73	
		XY	2262.33	
L-Ring Deployed	**Center of Gravity [mm]**	**X**	3.08	
		Y	32.41	
		Z	20.79	
	Moment of Inertia [kgmm²]	**X**	193119.52	
		Y	163396.92	
		Z	355146.61	
	Product of Inertia [kgmm²]	**YZ**	-106.07	
		XZ	-8.76	
		XY	1870.26	
S-Ring	**Center of Gravity [mm]**	**X**	0.00	0.00
		Y	0.00	0.00
		Z	39.74	40.79
	Moment of Inertia [kgmm²]	**X**	29679.52	34489.59
		Y	29679.52	34489.59
		Z	59321.91	68931.59
	Product of Inertia [kgmm²]	**YZ**	0.00	0.00
		XZ	0.00	0.00
		XY	0.00	0.00
Combined System Stowed	**Center of Gravity [mm]**	**X**	2.60	2.53
		Y	27.58	26.93
		Z	22.38	22.97
	Moment of Inertia [kgmm²]	**X**	222826.83	227770.84
		Y	192814.17	197682.14
		Z	414615.48	424302.56
	Product of Inertia [kgmm²]	**YZ**	-294.19	-363.25
		XZ	-26.67	-33.17
		XY	2315.54	2322.76

B

Appendix

Mounting Interface Specifications

CarboNIX 8 S-Ring ST

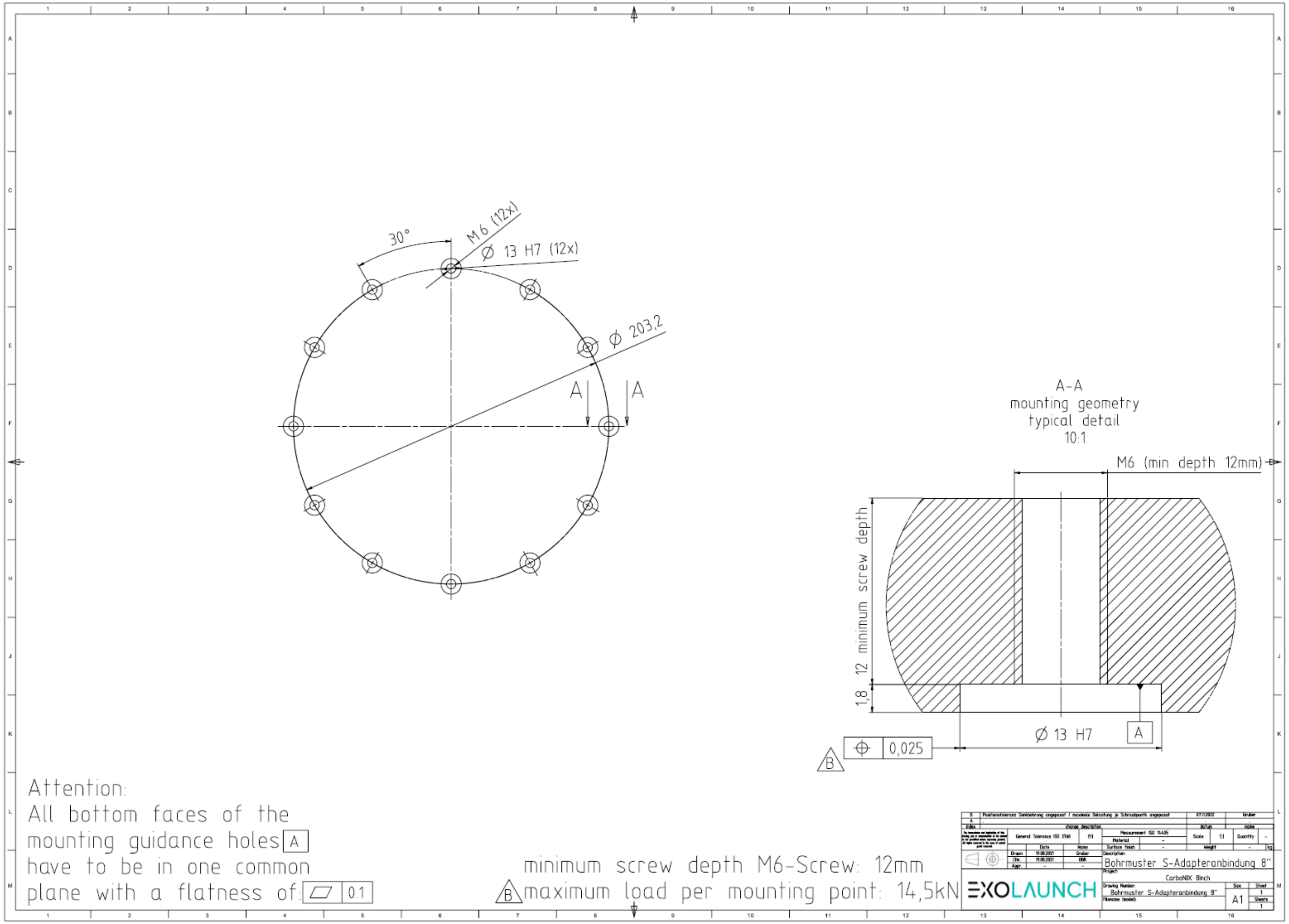


Figure 49: Satellite Interface Definition for CarboNIX 8 ST.

CarboNIX 8 S-Ring IM

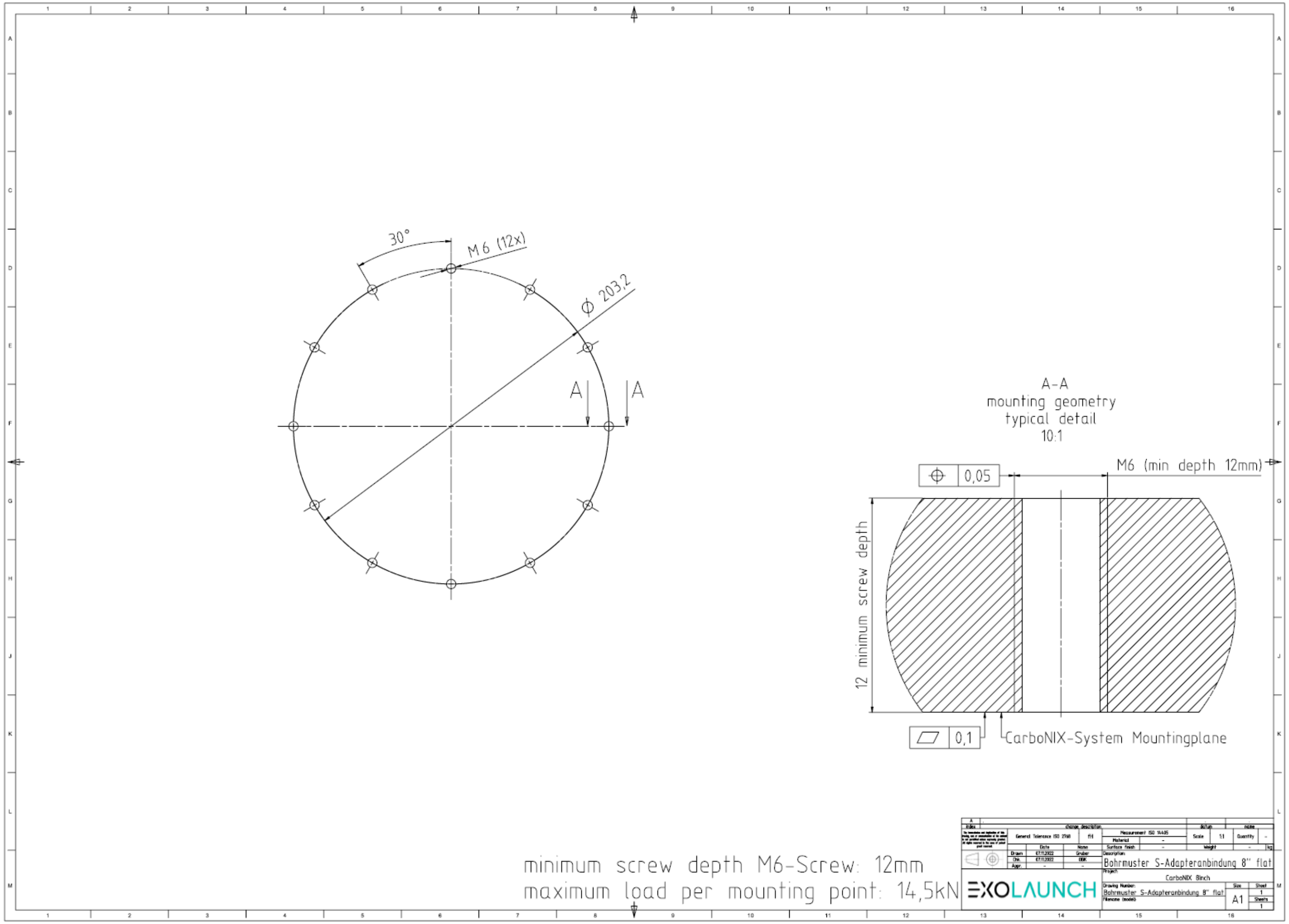


Figure 50: Satellite Interface Definition for CarboNIX 8 IM.

CarboNIX 8 L-Ring THRU

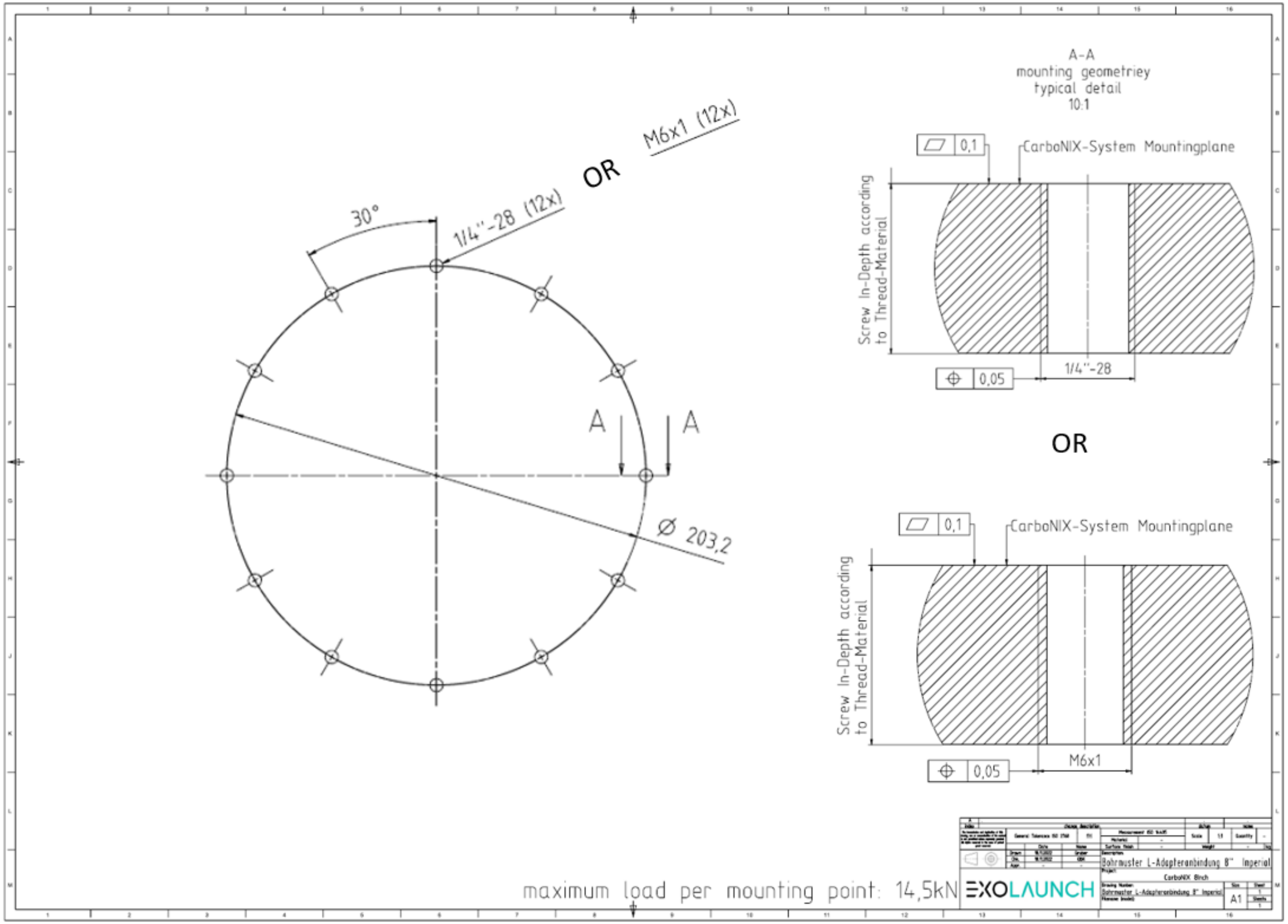


Figure 51: LV-Side Interface Definition for CarboNIX 8 with thru holes.

CarboNIX 8 L-Ring THREADS

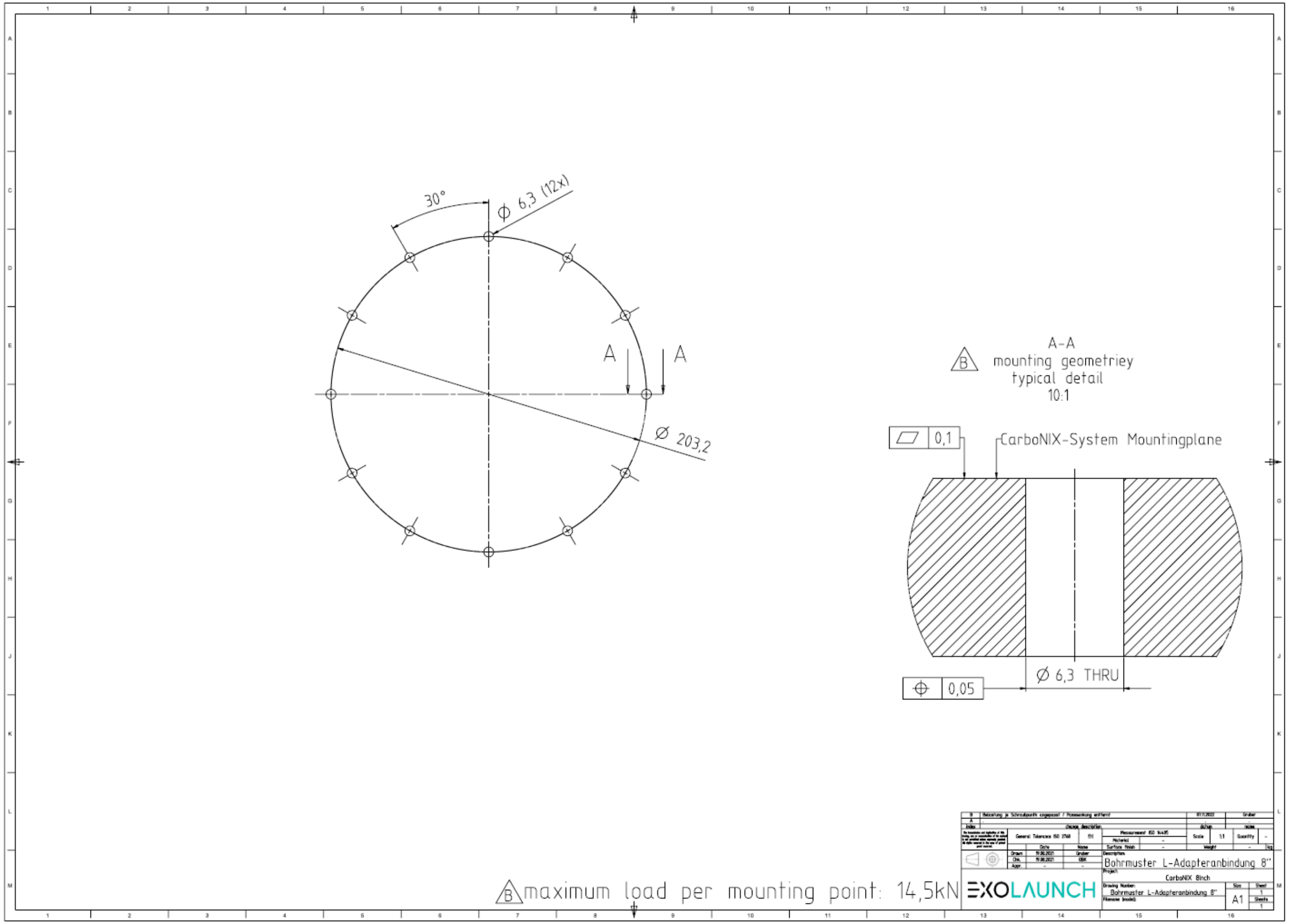


Figure 52: LV-Side Interface Definition for CarboNIX 8 with thru holes (not preferred).

CarboNIX 11.732 S-Ring ST

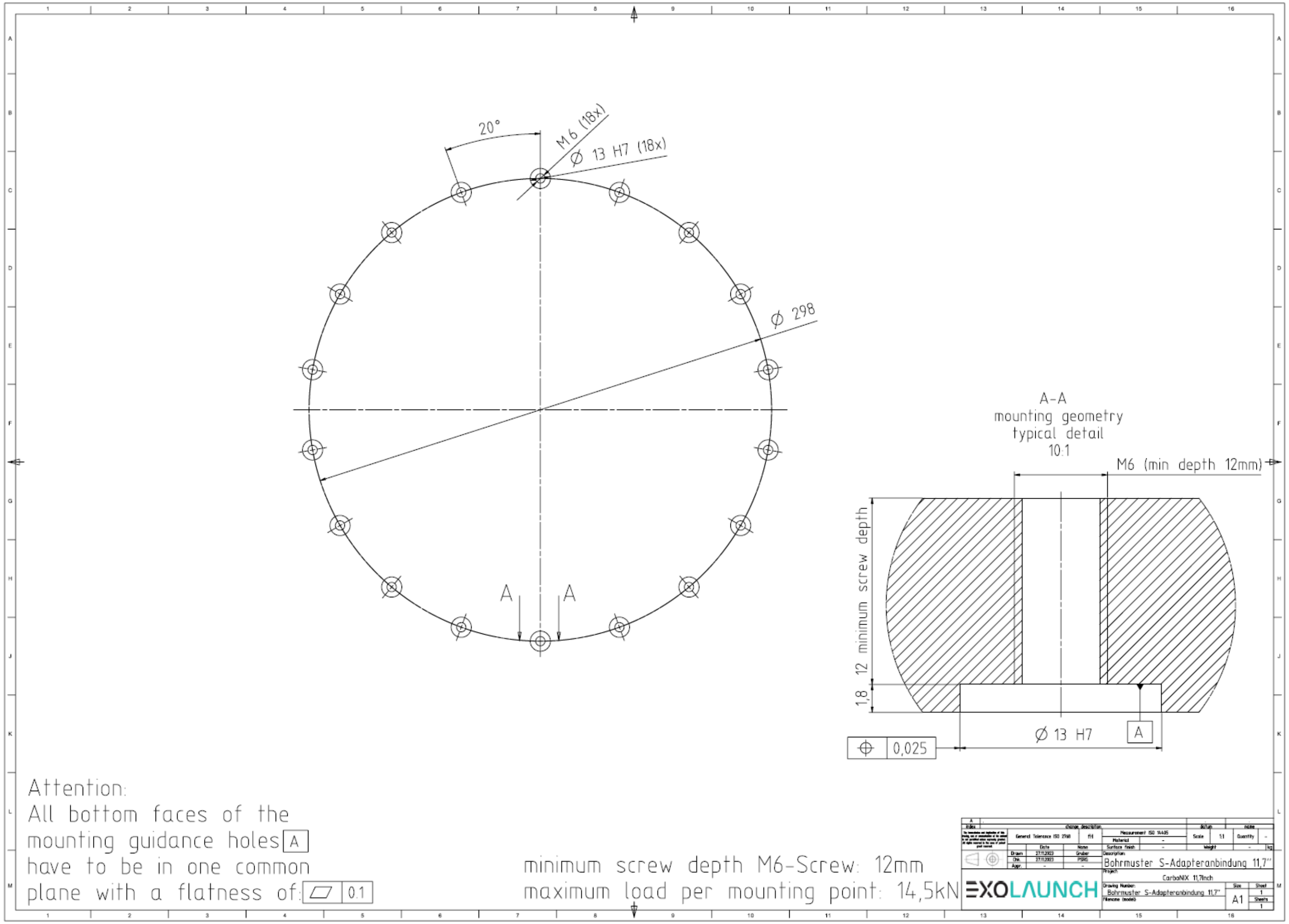


Figure 53: Satellite Interface Definition for CarboNIX 11.732 ST.

CarboNIX 11.732 S-Ring IM

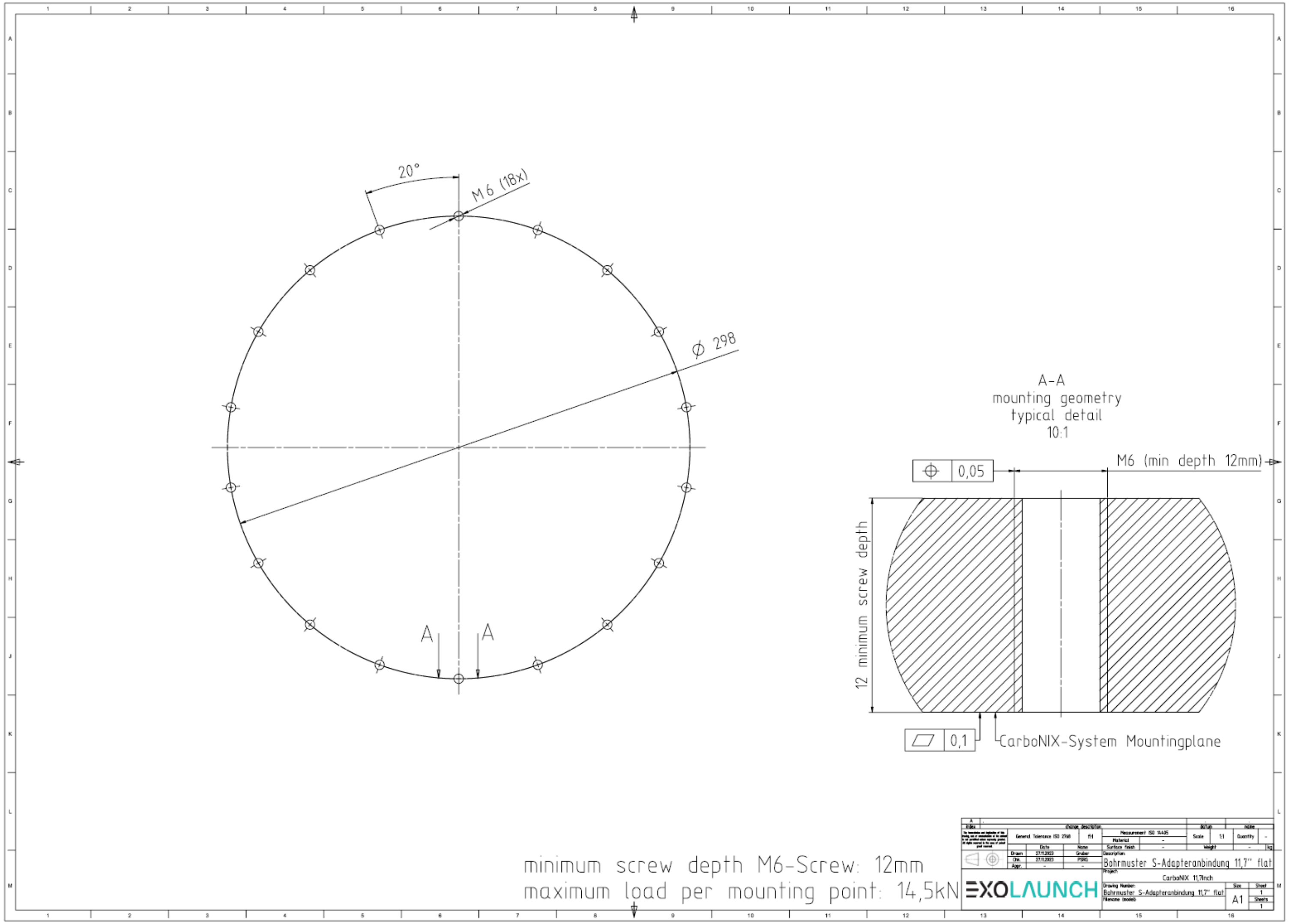


Figure 54: Satellite Interface Definition for CarboNIX 11.732 IM.

CarboNIX 11.732 L-Ring THRU

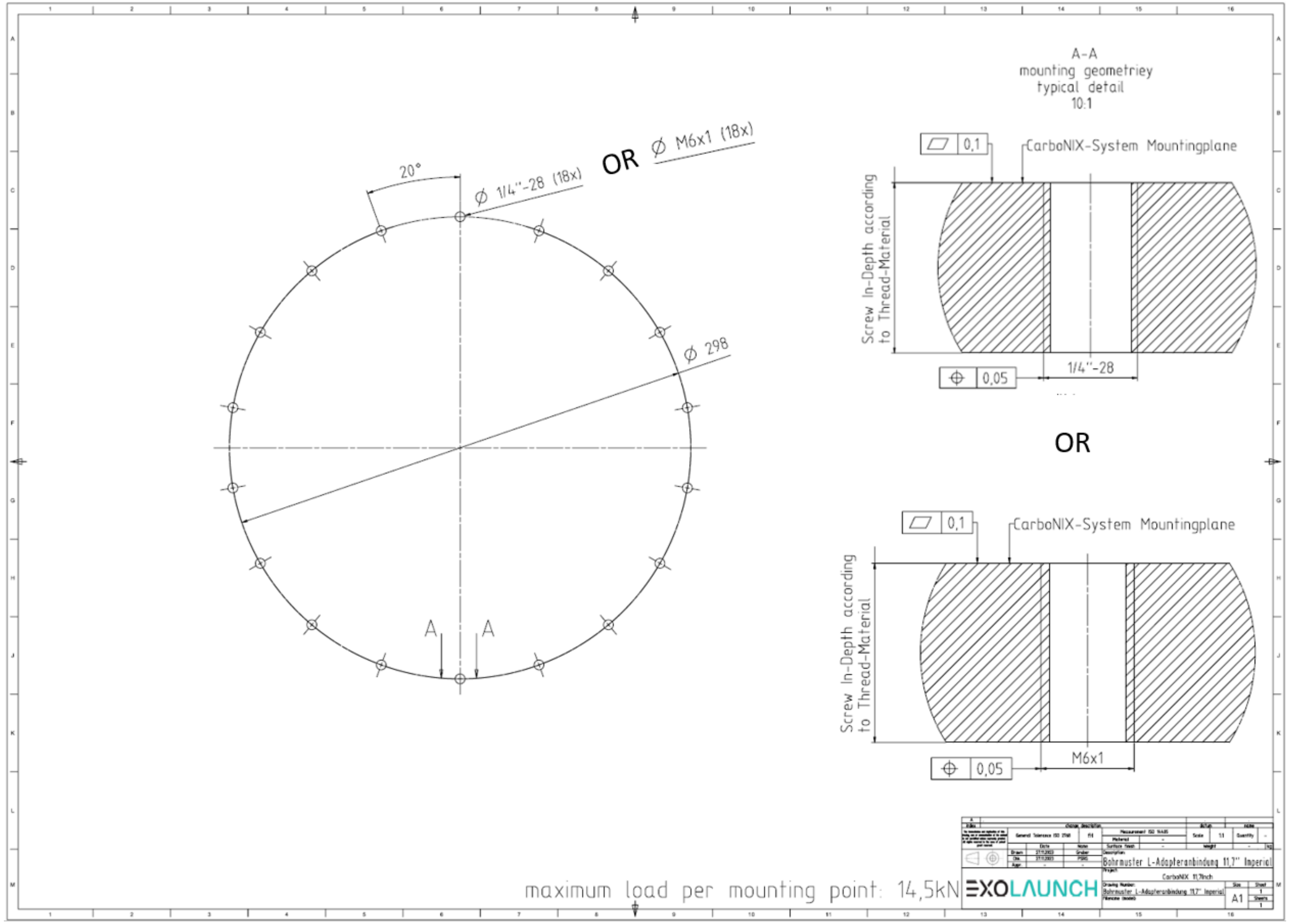


Figure 55: LV-Side Interface Definition for CarboNIX 11.732 with thru holes.

CarboNIX 11.732 L-Ring THREADS

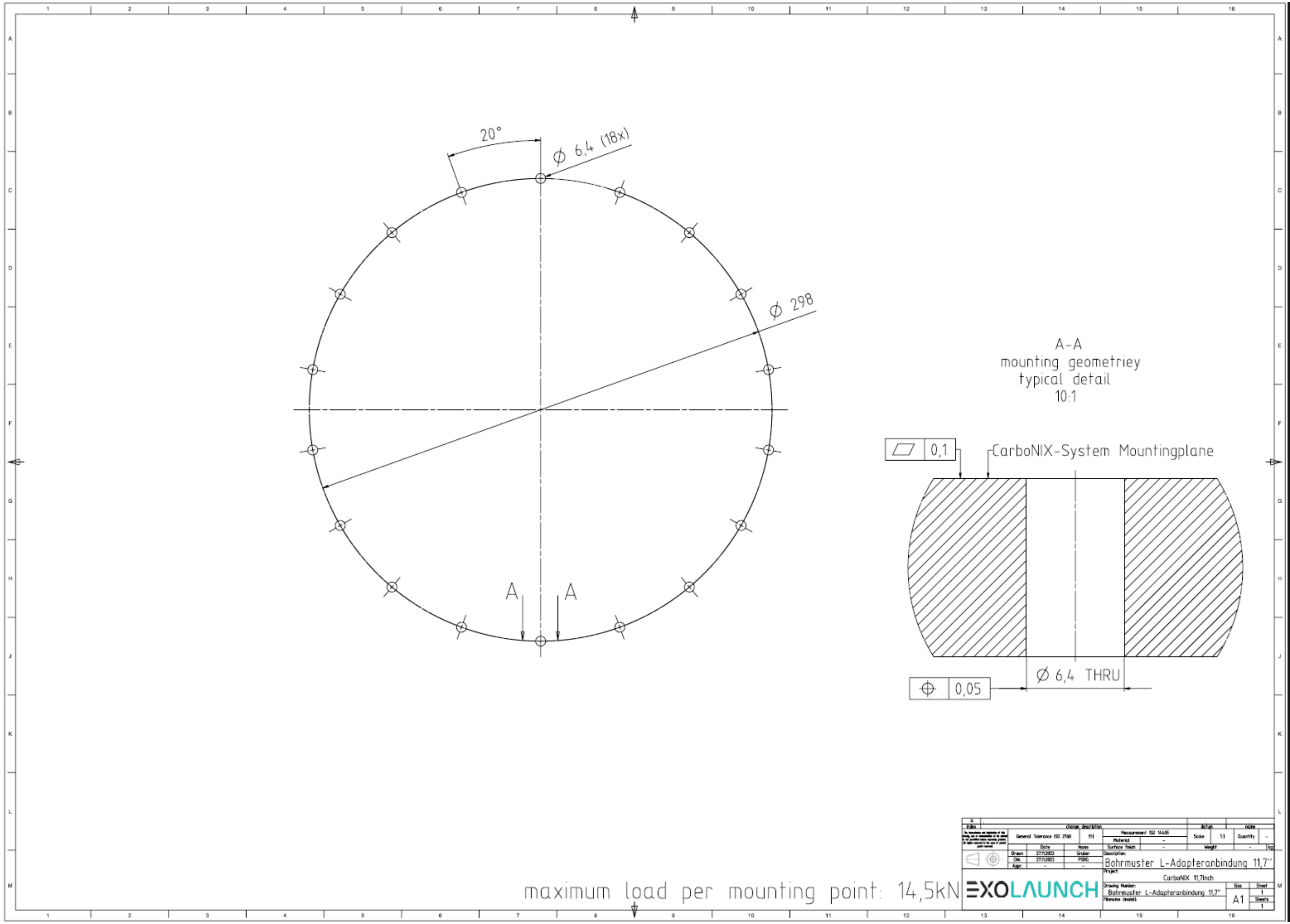


Figure 56: LV-Side Interface Definition for CarboNIX 11.732 with thru holes (not preferred).

CarboNIX 15 S-Ring ST

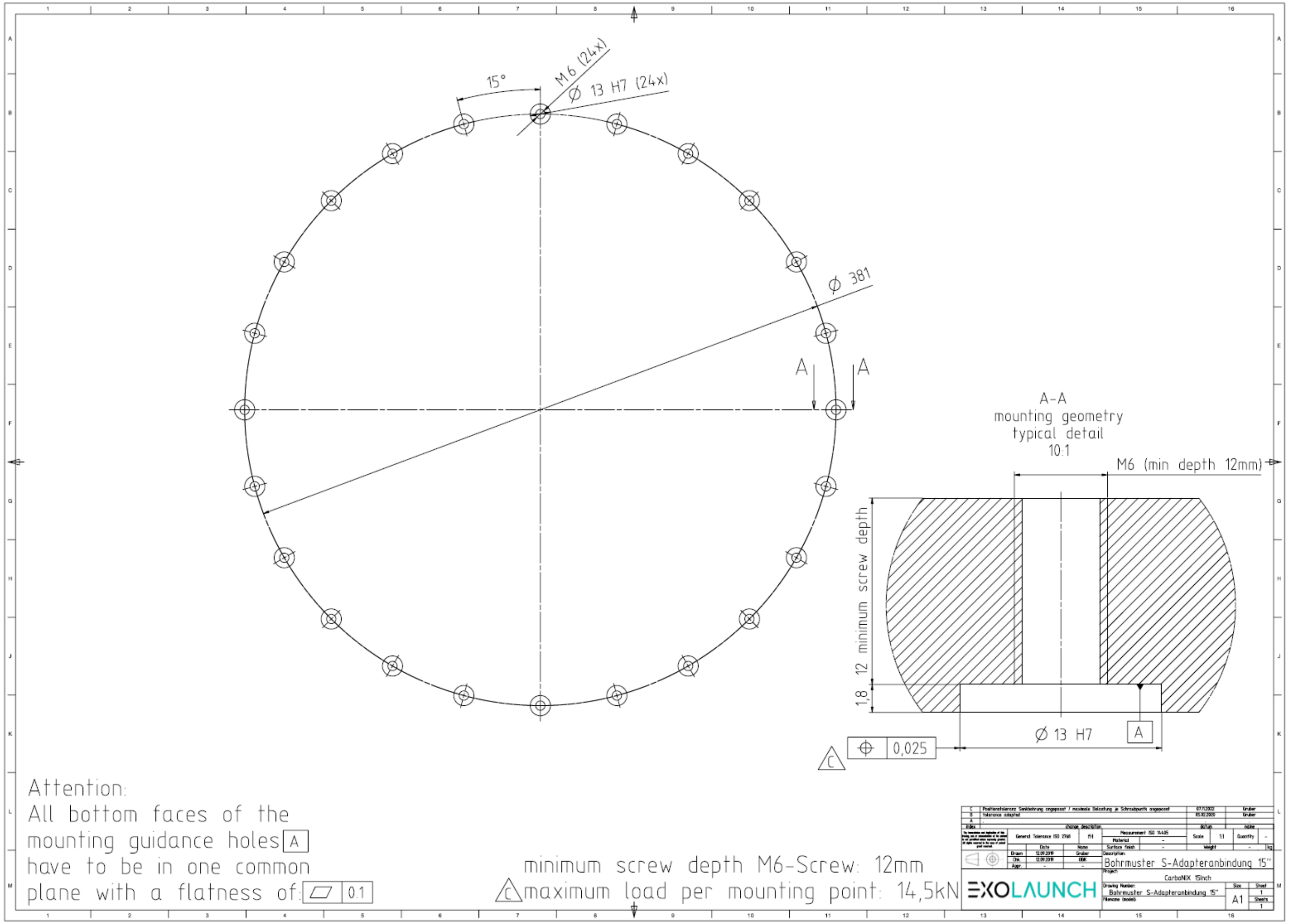


Figure 57: Satellite Interface Definition for CarboNIX 15 ST.

CarboNIX 15 S-Ring IM

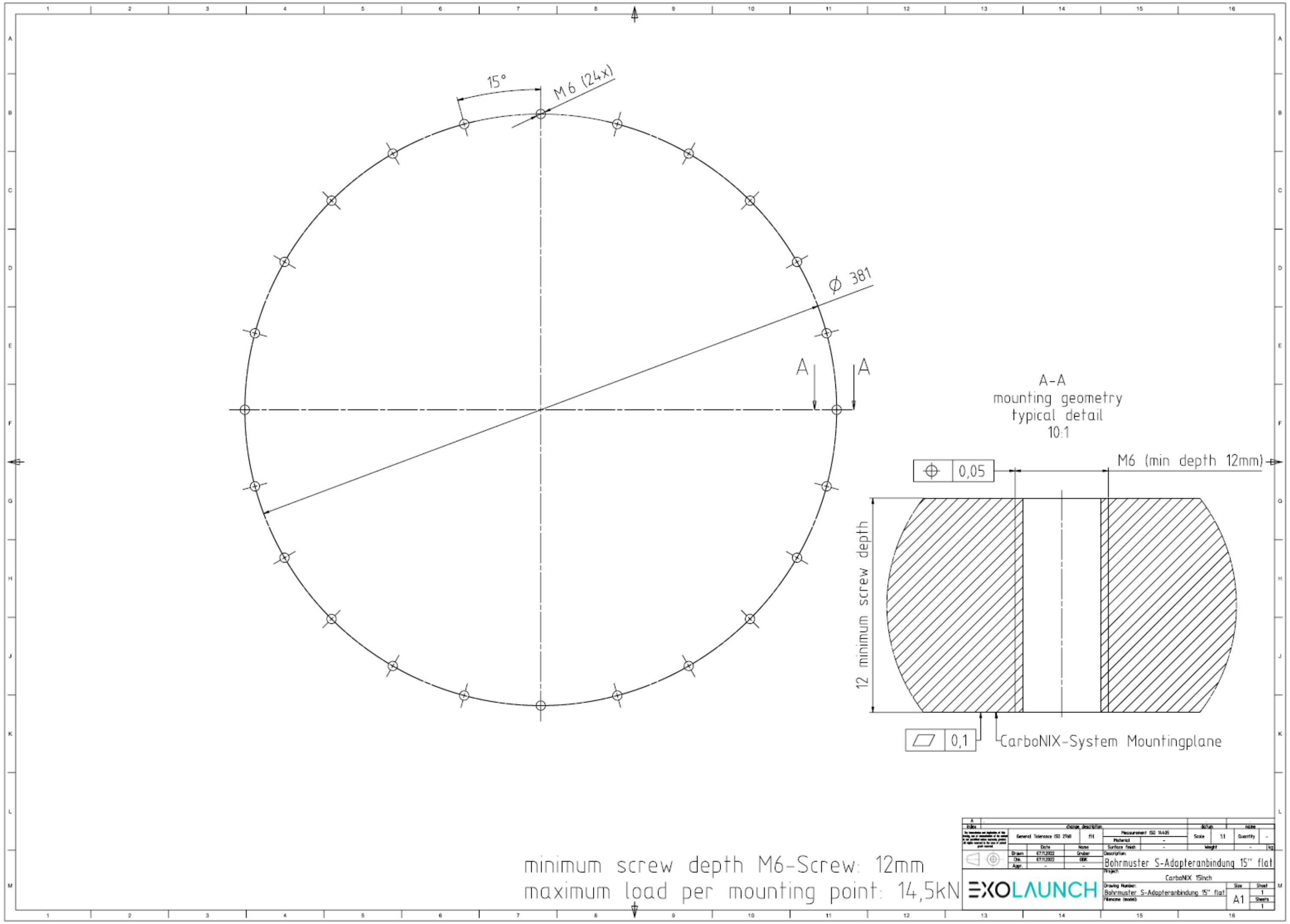


Figure 58: Satellite Interface Definition for CarboNIX 15 IM.

CarboNIX 15 L-Ring THRU

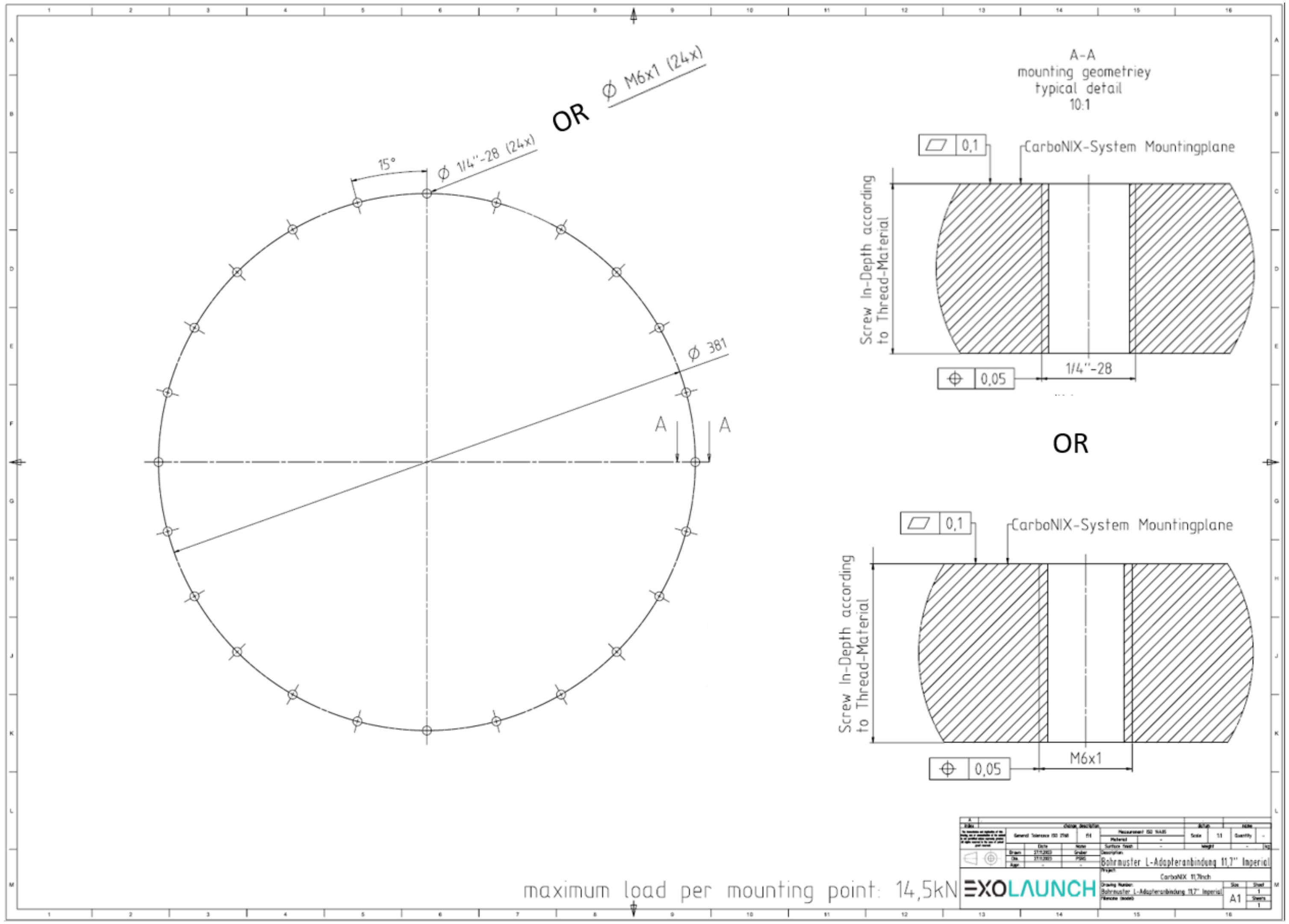


Figure 59: LV-Side Interface Definition for CarboNIX 15 with thru holes.

CarboNIX 15 L-Ring THREADS

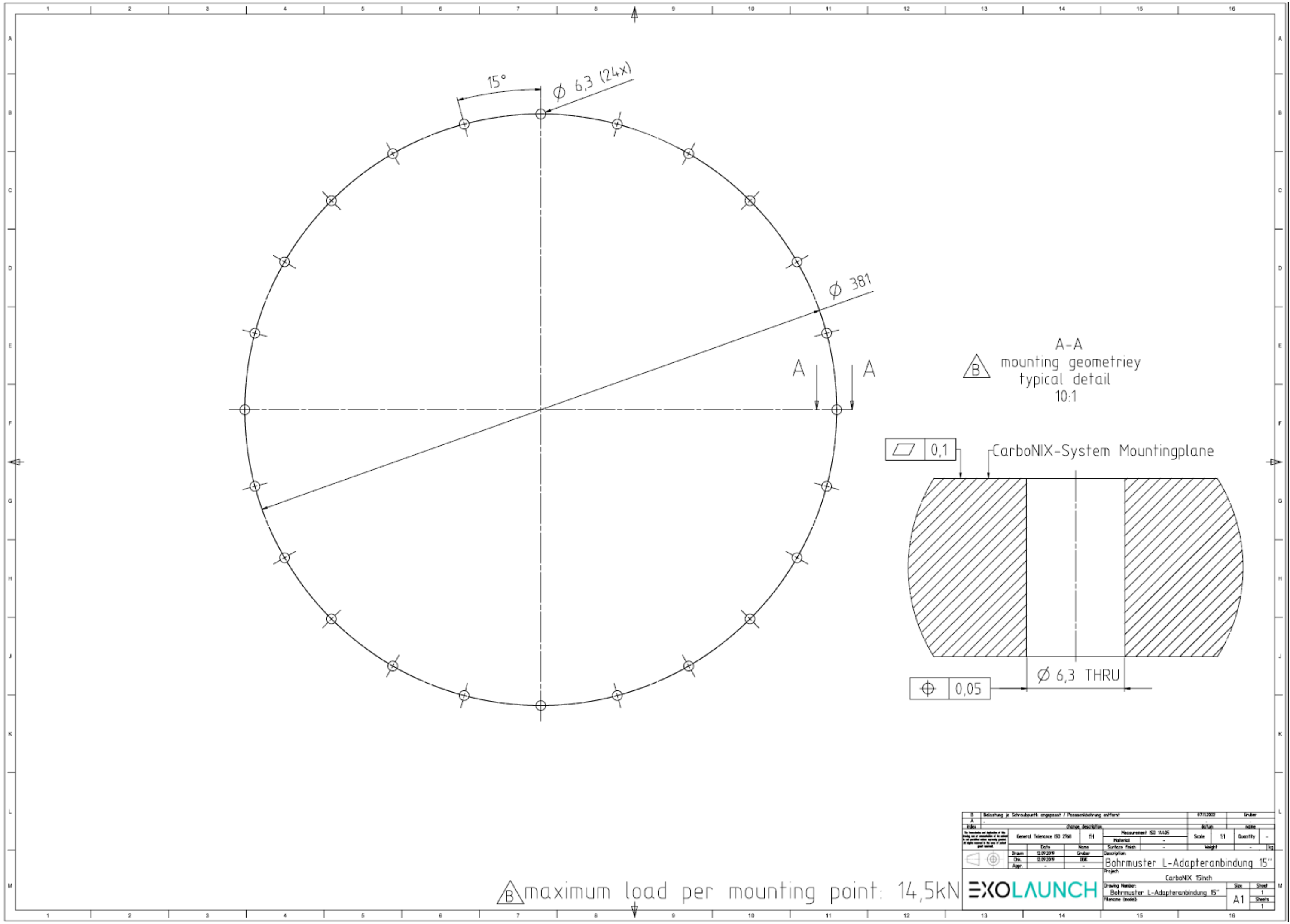


Figure 60: LV-Side Interface Definition for CarboNIX 15 with thru holes (not preferred).

CarboNIX 18.25 S-Ring ST

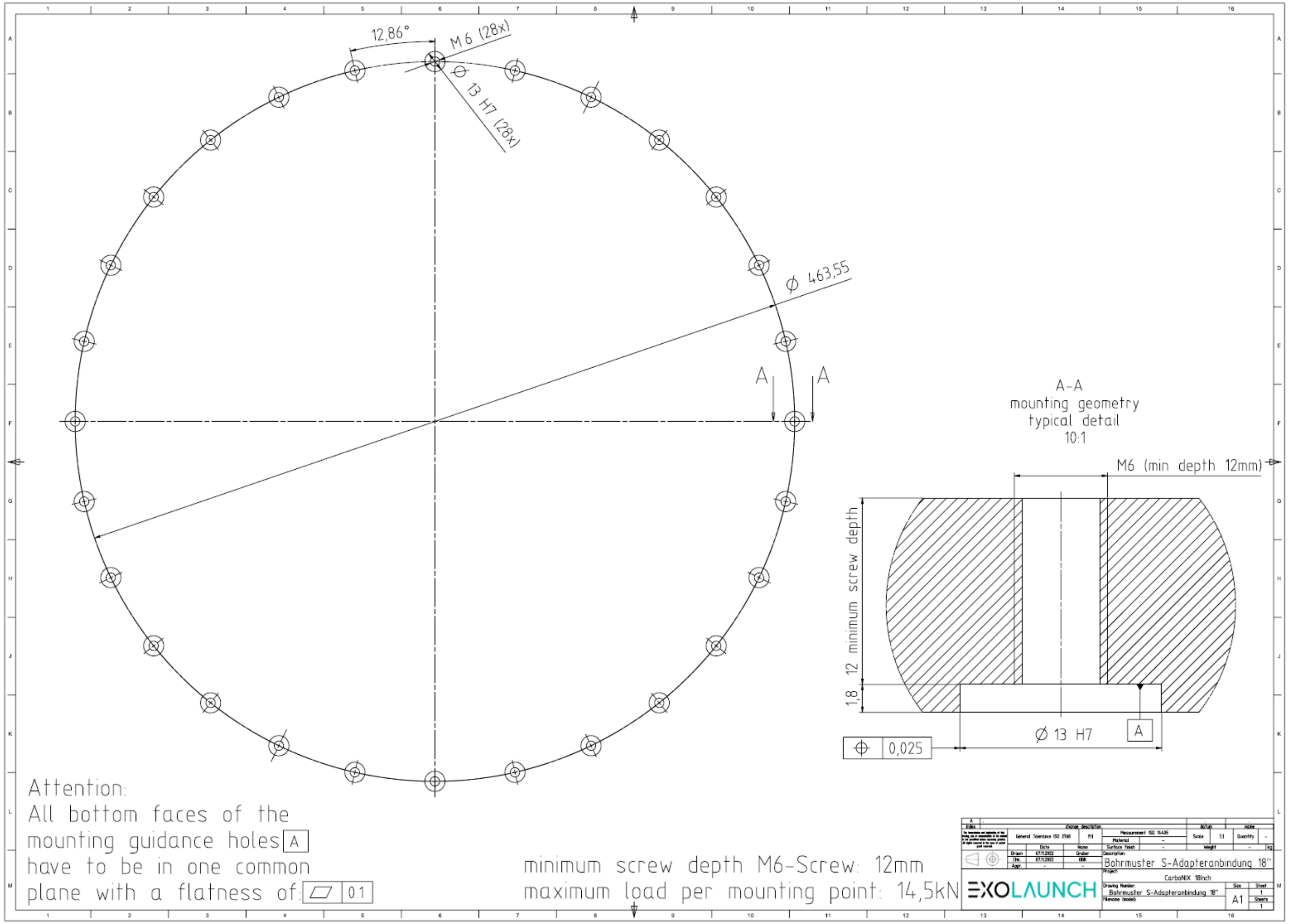


Figure 61: Satellite Interface Definition for CarboNIX 18.25 ST.

CarboNIX 18.25 S-Ring IM

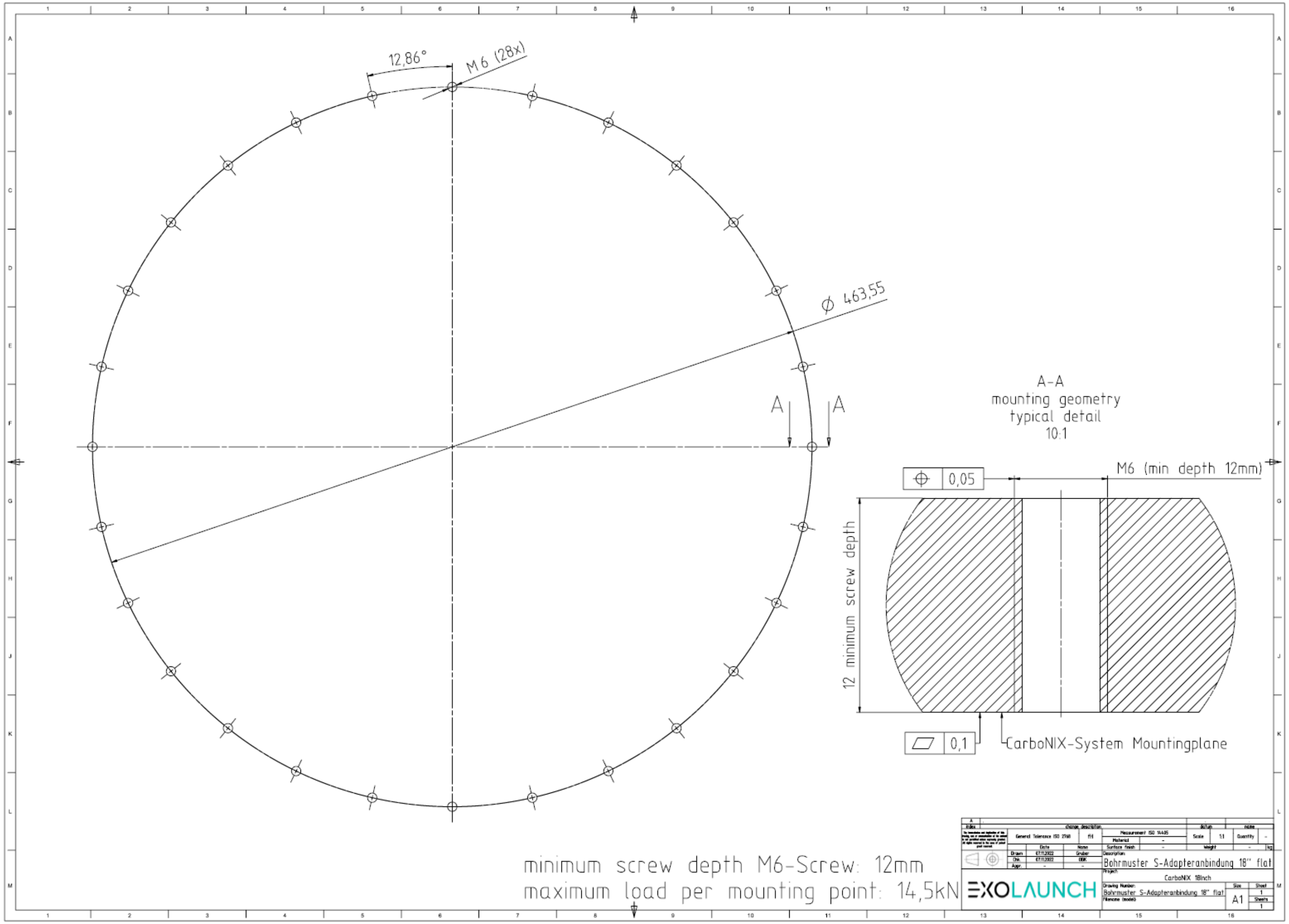


Figure 62: Satellite Interface Definition for CarboNIX 18.25 IM.

CarboNIX 18.25 L-Ring THRU

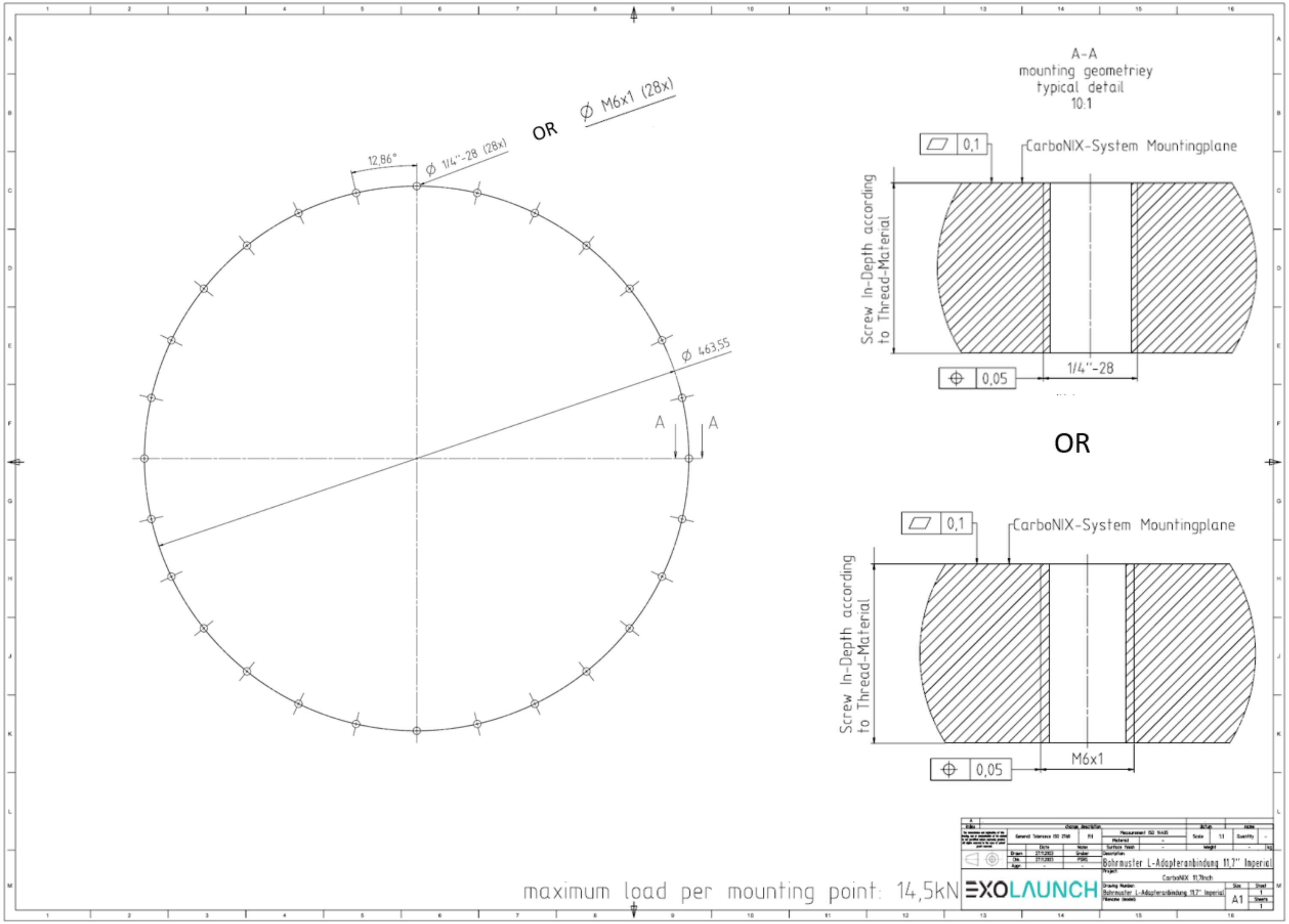


Figure 63: LV-Side Interface Definition for CarboNIX 18.25 with thru holes.

CarboNIX 18.25 L-Ring THREADS

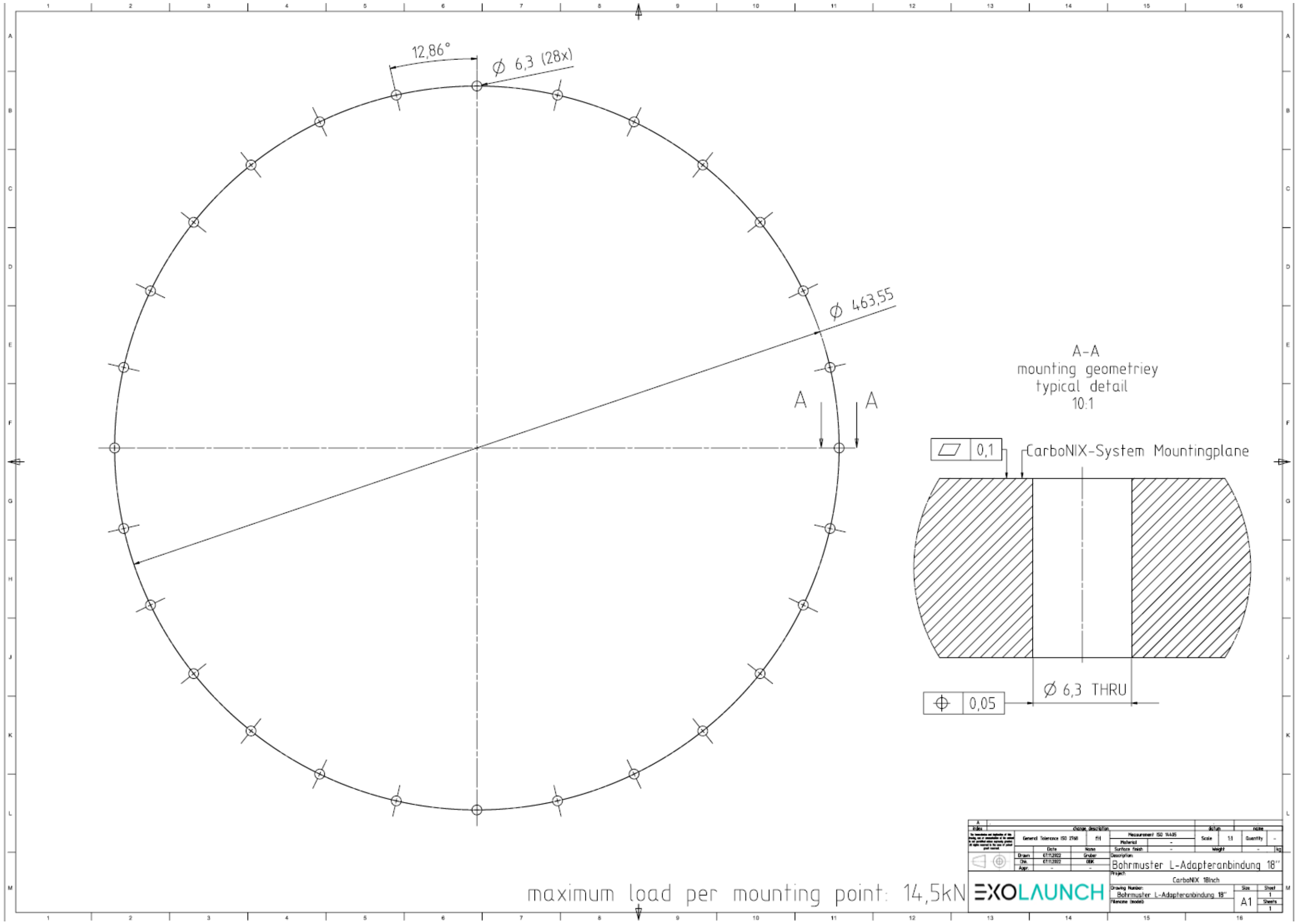


Figure 64: LV-Side Interface Definition for CarboNIX 18.25 with thru holes (not preferred).

CarboNIX 24 S-Ring ST

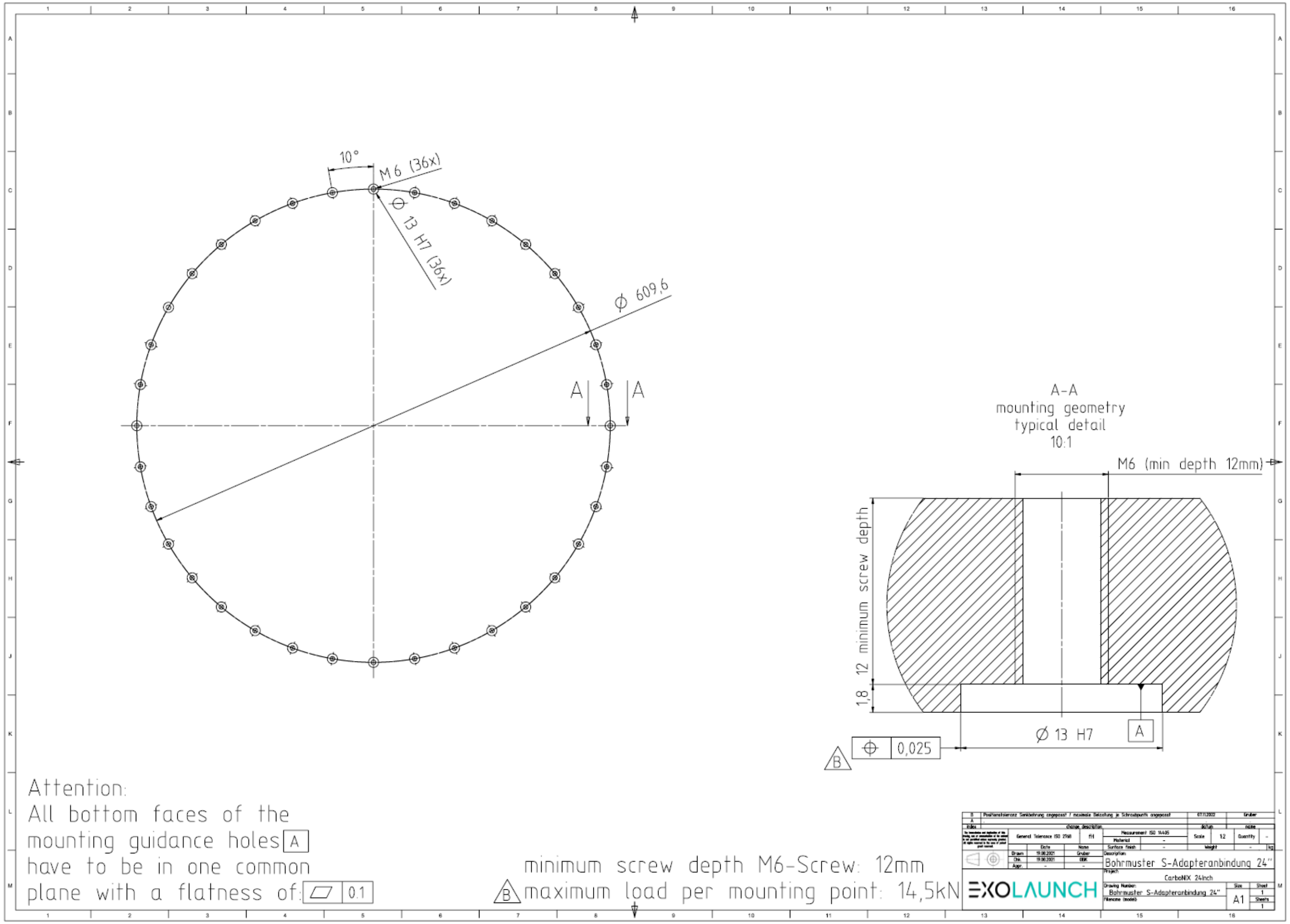


Figure 65: Satellite Interface Definition for CarboNIX 24 ST.

CarboNIX 24 S-Ring IM

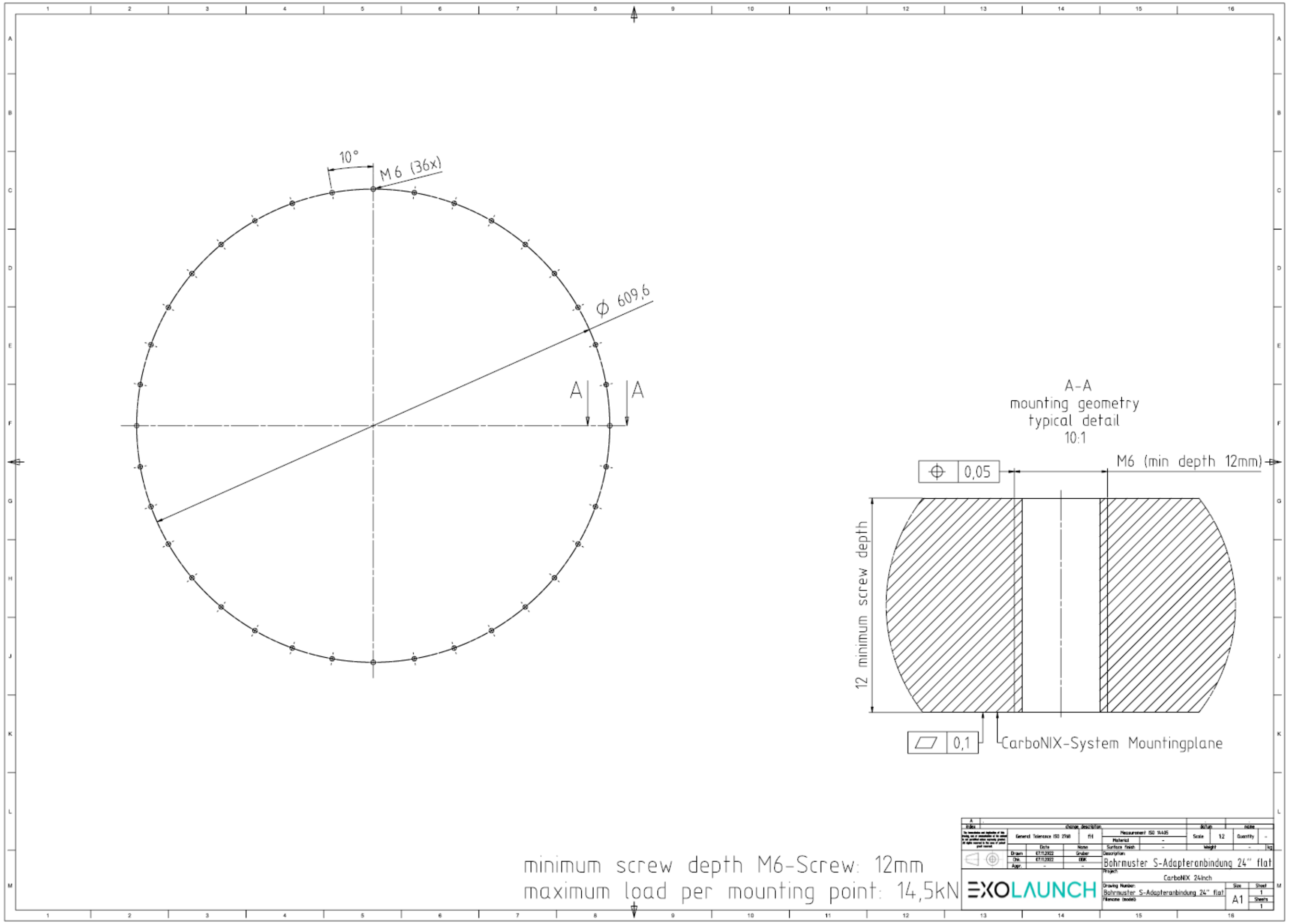


Figure 66: Satellite Interface Definition for CarboNIX 24 IM.

CarboNIX 24 L-Ring THRU

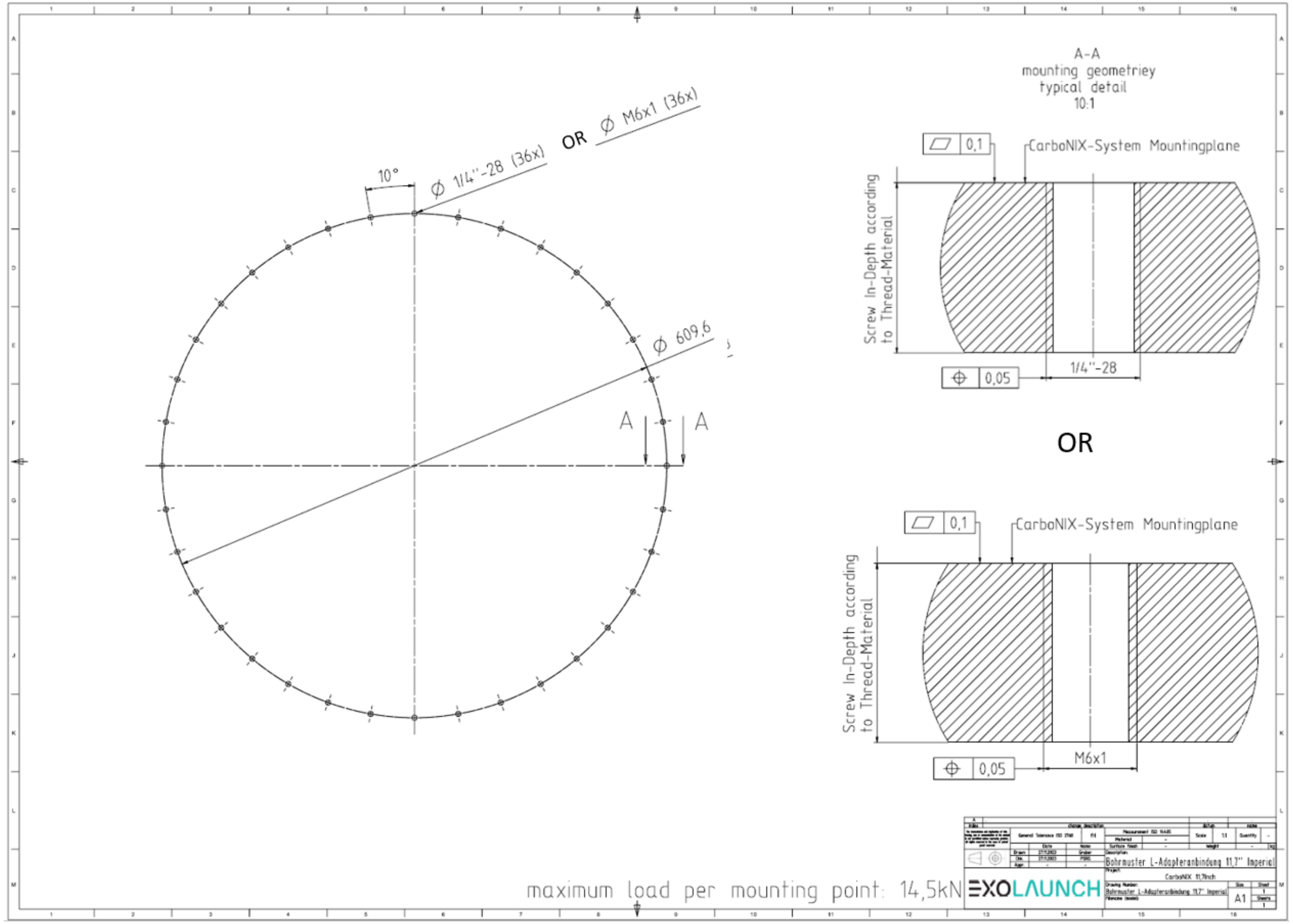


Figure 67: LV-Side Interface Definition for CarboNIX 24 with thru holes.

CarboNIX 24 L-Ring THREADS

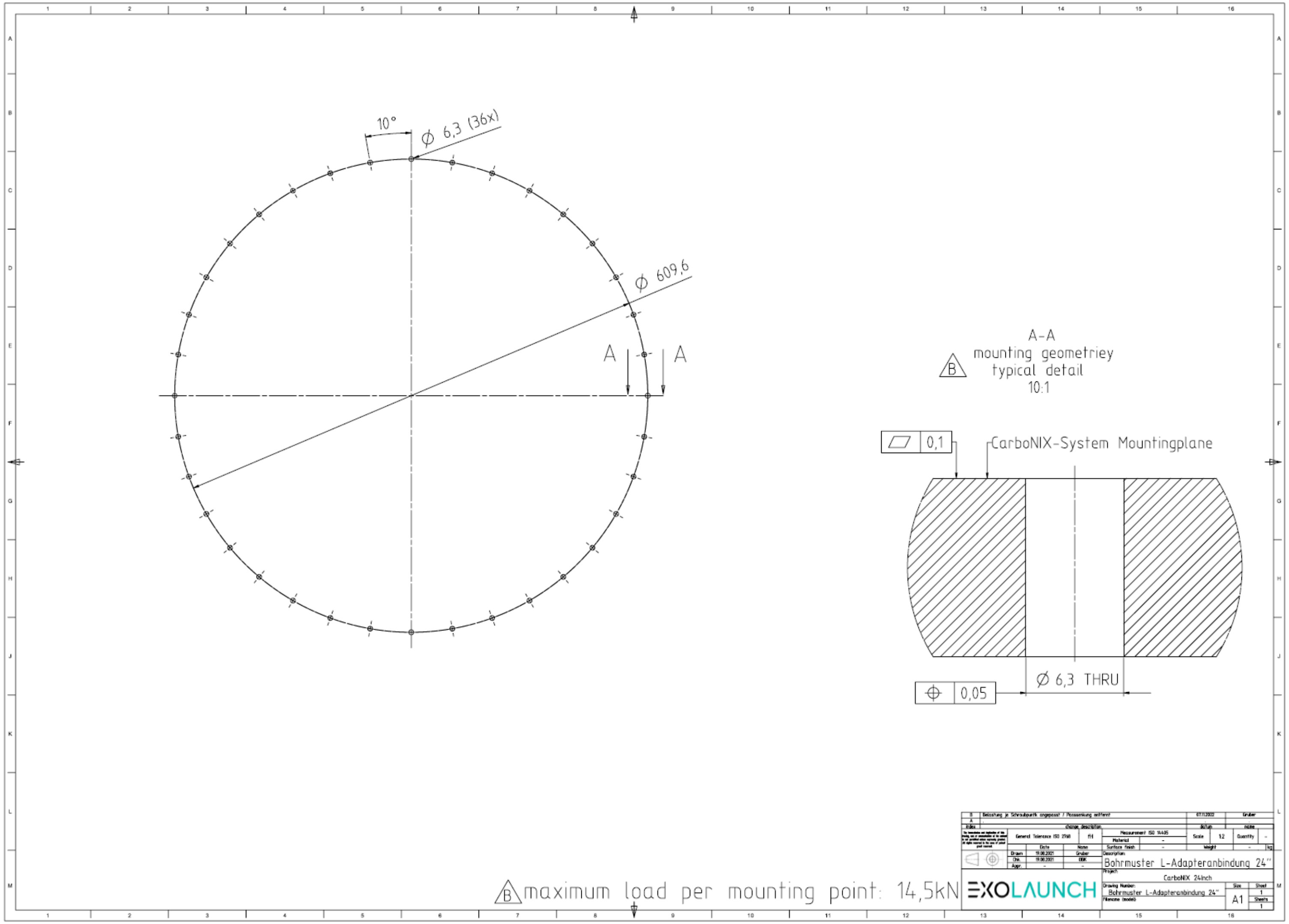


Figure 68: LV-Side Interface Definition for CarboNIX 24 with thru holes (not preferred).

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