Qualification of the Milli Release Nut (mD3RN) resettable SMA release nut for SmallSat Hold-Down and Release Applications

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Abstract—The Dcubed Milli Release Nut (mD3RN) is a compact, high-performance release actuator based on Shape Memory Alloy (SMA) technology, capable of sustaining and releasing axial loads of up to 15 kN. The actuator has been designed with a strong focus on low mass, compact form factor, and functional redundancy, while enabling a simple and rapid reset procedure that can be performed without the need for external tools. This paper presents the qualification campaign carried out for the mD3RN, encompassing vibration, shock, and thermal vacuum (TVAC) testing, as well as an extensive life-cycle assessment. The test results confirm the actuator's reliability in representative space environments and demonstrate its capability for rapid and repeatable reset, making it suitable for a wide range of space applications.

Keywords**—**hold-down and release mechanism; HDRM; release nut; shape memory alloy; SMA; small satellites; qualification; vibration; shock; thermal vacuum.

I. INTRODUCTION

Small-satellite programs increasingly depend on deployable structures such as solar arrays, antennas, radiators, optical covers, drag devices, and payload doors. These subsystems must remain restrained during ground handling and launch, then release predictably in orbit. Pyrotechnic devices remain attractive where very high force margins are required, but their one-shot behavior, emitted shock, storage and handling constraints, and limited reset capability can be misaligned with the rapid integration and repeated test cadence of small-satellite missions.

The Dcubed Milli Release Nut (mD3RN) addresses this integration space with a resettable, non-pyrotechnic, shape-memory-alloy (SMA) release-nut architecture. Rather than demonstrating a single release event, qualification must show that the actuator survives the combined sequence relevant to flight hardware: preload application, repeated resets, sine and random launch vibration, mechanical shock, thermal-vacuum exposure, and final actuation at mission-relevant temperature. This paper summarizes the qualification campaign and discusses the resulting application envelope for SmallSat Hold-Down and Release Mechanisms (HDRMs).

For a resettable release device, qualification evidence has two dimensions. The first is environmental survival: the unit must remain structurally and electrically intact after the mechanical and thermal environments imposed by launch and early orbit. The second is operational durability: the same unit may be used through several engineering-model, qualification-model, acceptance, and system-level deployment tests. These repeated actuations consume reset life, and the acceptable number of resets depends on preload. The campaign was therefore designed to link environmental survivability with preload-dependent life-cycle evidence rather than treating the release nut as a one-shot item.

II. ACTUATOR ARCHITECTURE

The mD3RN is an SMA-based release actuator that restrains axial tensile preload through an internal nut and releases it by Joule heating of internal SMA elements. The actuator configuration has a cylindrical 56 mm by 55 mm envelope and a mass of 225 g. The body uses hard-anodized aluminum 6082-T6 and titanium grade 5 components, while the nut is 17-4PH stainless steel. The standard mechanical interface uses six M4 mounting threads and an M8 threaded nut interface. The actuator is intended primarily for axial preload; shear loads should be managed at spacecraft level, for example, through cup-cone interfaces or equivalent alignment features.

TABLE I. KEY MD3RN CONFIGURATION DATA

Envelope / mass: 56 mm dia. x 55 mm; 225 g
Structural interface: 6 x M4 mounting; M8 nut thread
Nominal axial rating: 15 kN;
Operating range: -65 deg C to +75 deg C
Actuation interface: 2 independent wire pairs, 24-32 V
Resistance: 37 Ohm +/- 2 Ohm at room temperature
Reset capability: Rapid reset, on ground and in space

Two independent actuation circuits provide functional redundancy. The yellow-yellow pair is the primary circuit and the red-red pair is the redundant circuit. Each circuit behaves as a resistive load with no polarity requirement. The specified room-temperature resistance is 37 Ohm +/- 2 Ohm, the actuation lead interface is 22 AWG silver-plated copper with PTFE insulation, and the recommended command voltage range is 24 V to 32 V. Because release is driven by thermal activation, trigger time depends on voltage, preload, and actuator temperature. At 24 V and 9 kN preload in vacuum, representative trigger times are 7-8 s at -65 deg C, 3-4 s at 0 deg C, and 1.5-2 s at +75 deg C.

The reset concept is deliberately simple. After actuation and cool-down, the released nut is reinserted into the actuator shaft while maintaining alignment with the actuation direction. The nut is driven to the bottom position until the mechanism engages, then the reset state is verified by a pull check. This reset procedure is a major operational advantage during satellite integration because it allows repeated deployment rehearsals without refurbishment of a pyrotechnic cartridge or replacement of a frangible element. At the same time, the procedure introduces a need for configuration control: each actuation should be recorded with preload, circuit, command duration, temperature, and post-reset verification results.

III. QUALIFICATION APPROACH

The qualification logic was selected to cover the environmental and functional risks most relevant to a resettable HDRM. Vibration testing verifies launch-load survival and checks that resonance behavior does not change significantly. Shock testing verifies survival against a high-frequency shock-response-spectrum (SRS) environment. Thermal-vacuum cycling verifies environmental compatibility across the specified temperature range under high vacuum. Finally, reset cycling characterizes the relationship between preload and number of successful actuations, which is essential because a resettable actuator may be used across multiple subsystem and system-level tests before flight.

The campaign used external test laboratories for mechanical and thermal environments. Vibration testing was performed at ZARM-FAB using an LDS V875-440 shaker system. Shock and thermal-vacuum testing were performed at KRP Mechatec. Post-test reviews recorded test completion, deviations, nonconformance status, and open work. The qualification evidence therefore, combines measured environmental exposure, inspection results, and functional operation.

The evidence chain was intentionally conservative. Resonance surveys before and after high-level vibration runs were used to identify changes that would indicate loosening, cracking, or structural degradation. Shock testing used average SRS data from sensors in the shock direction and included repeat runs. Thermal-vacuum cycling used dwell-based acceptance at both temperature extremes. Reset cycling was then performed to failure of preload retention, so the resulting values represent the onset of the practical life limit under the tested conditions, not only a pass/fail demonstration.

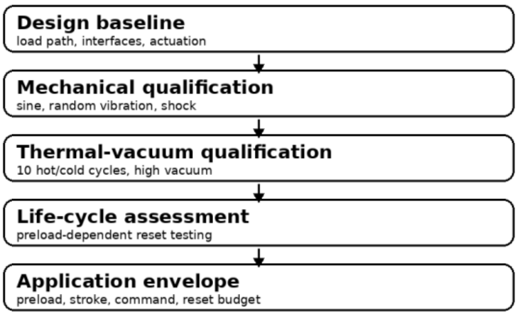

Fig. 1. Qualification flow used to link component test evidence to an application envelope.

TABLE II. QUALIFICATION TEST MATRIX

Resonance survey: 0.5 g, 5-2000 Hz before/after major vibration runs | Completed in all axes
Sine vibration: 24 g from 21-130 Hz, all axes | Technical integrity verified
Random vibration: 30.66 grms, 20-2000 Hz, 180 s/axis | Technical integrity verified
Shock: SRS 50 g at 100 Hz; 1500 g from 1-10 kHz | Technical integrity verified
TVAC cycling: 10 cycles, -65 deg C to +75 deg C, p < 1e-5 mbar | Technical integrity verified
Reset cycling: 6, 10, 14, 18 kN preload levels | Preload-dependent life characterized

IV. VIBRATION QUALIFICATION

Six mD3RN units were tested in all three orthogonal axes. Each axis used a low-level resonance survey, sine vibration, a second resonance survey, random vibration, and a third resonance survey. The resonance survey level was 0.5 g over 5-2000 Hz with a 2 oct/min sweep rate. Sine vibration was applied at 24 g from 21 Hz to 130 Hz at 4 oct/min. Random vibration used the specified 20-2000 Hz power spectral density with 30.66 grms and a 180 s duration per axis.

The vibration report states that all three orthogonal axes were tested using the appropriate adapter configuration and that resonance surveys were carried out before and after each sine and random run to evaluate significant eigenfrequencies. Control and response monitoring used calibrated accelerometers on the adapter and on the mD3RN. The test outcome supports the conclusion that the actuator maintains technical integrity under the mechanical vibration environment used for the campaign. For system integrators, this confirms that the mD3RN can be carried through a representative launch-vibration sequence as part of an integrated deployable subsystem.

The resonance-survey comparisons are particularly relevant for a compact release nut because small internal changes can otherwise remain hidden until functional release. A shift in a dominant response peak, a new high-Q resonance, or a loss of repeatability between surveys would be a warning that the bolted interface, reset mechanism, or internal load path had changed. No such campaign-level failure was reported. The actuator response channels measured higher local accelerations than the control channels in some bands, as expected for a small unit mounted on an adapter, but these responses did not lead to test abort or post-test nonconformance. This supports the conclusion that the tested mounting configuration and actuator body can withstand the selected vibration environment.

V. SHOCK QUALIFICATION

Shock testing was performed on the same six mD3RN actuators. The test specification applied to the X, Y, and Z axes and used an SRS requirement of 50 g at 100 Hz and 1500 g from 1000 Hz to 10000 Hz. SRS calculation used a Q factor of 10, a frequency range of 100-10000 Hz, and 12 points per octave, with tolerances of -3 dB and +6 dB and at least 50 percent of the spectrum above the nominal level.

The shock test success criterion required plausible measured data without apparent sensor failure and applied shock loads meeting the specified levels and tolerances within the agreed setup limits. The post-test review recorded deviations caused by measurement malfunction or initially low SRS levels in selected runs. Low-SRS Y-axis runs were repeated until acceptable runs were obtained. The PTR concluded that the shock test had been performed successfully and released the campaign to continue with thermal-vacuum testing. Visual inspection reported no apparent damage on the tested actuator sets. This result is important because the actuator must not only be low shock during its own release event; it must also tolerate externally generated launch or separation shock from the spacecraft environment.

The shock campaign also illustrates a practical feature of component qualification: the applied shock environment is generated by the test setup and may require tuning to meet the target spectrum. The sequence included repeated Y-axis shocks because selected shots did not satisfy the 50 percent above-nominal criterion. These repetitions did not represent actuator functional failures; they were test-environment control issues that were corrected by additional runs. This distinction is important when using the report for spacecraft-level qualification planning. The final evidence is based on the accepted shock runs and the post-test review conclusion, not on the initial sub-tolerance impacts.

VI. THERMAL-VACUUM QUALIFICATION

The TVAC campaign required ten hot/cold cycles with ten temperature sensors on the samples, an upper plateau of +75 deg C with -10 deg C/+0 deg C tolerance, a lower plateau of -65 deg C with -10 deg C/+0 deg C tolerance, dwell times greater than 60 min, and chamber pressure below 1e-5 mbar. The procedure included sample inspection, sensor installation, pump-down, hot and cold dwells, repeated cycling, functional testing by Dcubed, return to room temperature, and post-test review.

The TVAC post-test review records that all test steps were performed, data were recorded and stored, test-facility documentation was available, no deviation from the test procedure occurred, no opened NCRs and the conclusion was that the test had been performed successfully. The overview data show ten cycles under high vacuum, with dwell times exceeding the 60 min requirement and sensor temperatures remaining inside the hot and cold tolerance bands. Example cycle data show a hot dwell of 1:09:23 and a cold dwell of 1:09:05 at pressure below 1e-5 mbar.

Thermal-vacuum evidence is central for an SMA actuator because actuation time is temperature-dependent. At cold conditions, the command duration must be long enough to heat the SMA to the release state; at hot conditions, the command must remain below the safe power application window. The TVAC result, therefore, supports environmental survivability and provides the context needed for command-duration sizing.

The TVAC configuration included the six mD3RN qualification units, with PT1000 sensors distributed across representative actuator positions and support structures. The temperature-extreme plots show that the coldest and hottest measured points remained inside the specified bands during the dwell periods, while the chamber pressure remained below the requirement. This matters for integration because the actuator body, nut, support plate, and harness experience different thermal time constants. Qualification based on sensor-level stabilization is, therefore, more meaningful than a chamber-only thermal cycle.

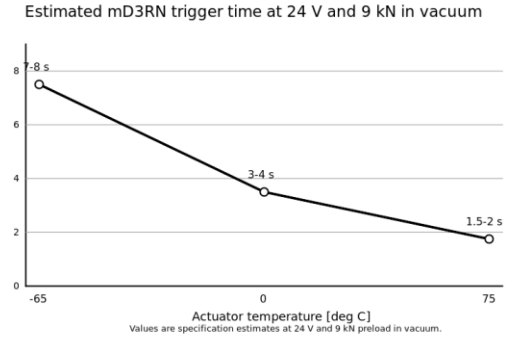

Fig. 2. Temperature-dependent trigger-time trend at 24 V and 9 kN preload in vacuum.

VII. RESET-CYCLE ASSESSMENT

Reset cycling was performed under laboratory conditions at 1 atm and 18-25 deg C. Preload was monitored with a calibrated Burster 8438-6050-N000S000 load cell and 9206-V0001 conditioning unit. After preload application, a two-minute wait was used to allow preload relaxation and stabilization before the trigger. The test note states that these actuations were performed in addition to actuations accumulated during TVAC and after vibration and shock testing. Actuators were tested until failure to hold preload occurred.

Using failure to hold preload as the end criterion makes the reset campaign directly relevant to HDRM use. The actuator does not merely need to move; it must return to a mechanically locked configuration that can sustain the specified preload until the commanded release. The two-minute stabilization period before each trigger also reflects a realistic integration issue: bolted and spring-loaded interfaces relax after torque application, and preload should be assessed after that relaxation, not only at the instant of tightening. The resulting data therefore characterize the combined reset, lock, and hold function.

TABLE III. RESET-CYCLE CHARACTERIZATION

6 kN: >100
10 kN: 88
14 kN: 15
18 kN: 2

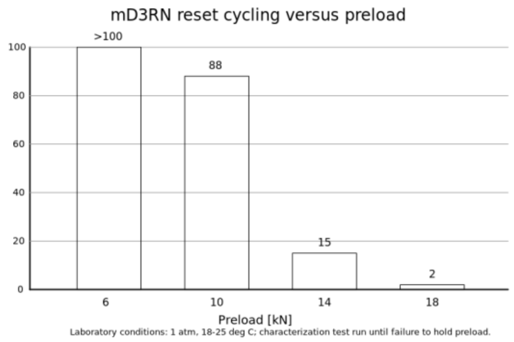

Fig. 3. Successful reset actuations as a function of preload under laboratory conditions.

The reset-cycle data show a strong preload dependence. At 6 kN, the test demonstrated more than 100 successful actuations, while 10 kN achieved 88 successful actuations. At 14 kN and 18 kN, successful actuation counts decreased to 15 and 2, respectively. The 18 kN point is treated here as a high-preload life-cycle characterization point, while the nominal product rating remains 15 kN unless a mission-specific configuration is agreed upon. This distinction is important for test planning: the ability to reset many times at moderate preload does not imply unlimited resets at maximum preload.

For program planning, the useful result is not only the maximum demonstrated actuation count. The shape of the preload-life trend indicates that a moderate preload regime can support extensive ground testing, while the highest-preload regimes should be reserved for qualification and acceptance events with a controlled number of repetitions. A flight program can therefore use a lower-preload engineering test configuration for deployment rehearsals, then move to the final preload for environmental acceptance and final functional verification. This preserves reset-life margin while still taking advantage of the actuator's reusability.

VIII. INTEGRATION IMPLICATIONS

A. Command duration and redundancy

The spacecraft release command should energize only one actuation circuit at a time. The redundant circuit provides a second independent release path, but simultaneous activation is not an acceptable method for increasing release speed.

Command duration should be selected from worst-case voltage, preload, and temperature rather than from room-temperature test results alone. A bounded maximum energization time, fault-protection logic, and cool-down interval between repeated release attempts should be included in spacecraft avionics design.

B. Preload, pull-out stroke, and shear

The preload system should provide the required hold-down force while ensuring that the nut fully clears the mechanism after release. A spring element, for example, a Belleville washer stack, should provide at least 3 mm of pull-out displacement. The mD3RN should be integrated so the dominant load path is axial. Where deployable geometry creates lever arms or non-perpendicular release motion, cup-cone or equivalent features should remove shear load from the actuator and should use material pairings and clearances compatible with vacuum, thermal expansion, and cold-welding constraints.

C. Reset-cycle budgeting

For programs that use the same hardware through qualification, acceptance, system test, and flight, resets should be treated as a finite life resource. A reset log should record serial number, circuit used, preload, voltage, current if available, command duration, temperature, reset operator, post-reset pull check, and any abnormal observation. The log links component-level qualification evidence to the actual mission configuration and supports acceptance decisions before final integration.

The system-level release design should also account for the fact that release-nut actuation is only one part of deployment. The released nut must clear the mechanism, the retained structure must begin moving with sufficient margin, and harness or thermal-blanket constraints must not reintroduce load into the release path. Functional release checks after vibration and TVAC should therefore use the representative preload stack, pull-out spring, deployment angle, and harness routing. These checks convert the component qualification evidence into confidence that the spacecraft deployment sequence will proceed without local interference.

IX. Application-Level Verification

Component qualification does not remove the need for application-level verification. A release nut is part of a preload, separation, and deployment chain; the final reliability depends on the integrated system as much as on the actuator. The most important system-level variables are the retained mass, launch load cases, fastener stiffness, spring-stack stiffness, friction in the deployment path, thermal gradients, harness routing, and the command sequence implemented in the spacecraft avionics. These parameters should be verified in the final geometry because small changes can alter the preload at the nut or the stroke required to clear the mechanism.

A recommended verification flow begins with preload correlation. The torque applied to the fastener should be converted into measured preload using representative flight hardware, including surface finish, lubrication state if any, washer stack, and interface stiffness. After preload application, the assembly should be allowed to relax before measurement. This is consistent with the reset-cycle test method and avoids accepting a preload state that exists only immediately after tightening. For highly thermally sensitive structures, preload should be checked after representative hot and cold exposure or verified analytically with conservative coefficients of thermal expansion.

The second step is separation verification. The mD3RN releases the nut, but the spacecraft mechanism must provide the stored energy needed to pull the nut out of the shaft and move the deployable away from the interface. A Belleville washer stack or equivalent preload spring should be designed to provide both the required hold-down load and the 3mm displacement required to disengage the nut. The separation margin should be demonstrated in the worst-case deployment orientation, including harness forces, hinge friction, and any gravitational offload or compensation used during ground test.

The third step is command verification. The actuation command duration should be derived from the coldest credible actuator temperature, the lowest bus voltage, the maximum expected preload, and the maximum allowable heating time. A simple and robust implementation is to command the primary circuit for a bounded time window, monitor deployment status if the spacecraft provides telemetry, and only then consider a redundant-circuit retry after the specified cool-down interval. The command should not energize both circuits simultaneously. Ground test should verify the release timing with the same voltage and wiring losses expected in the spacecraft harness.

TABLE IV. RECOMMENDED SYSTEM-LEVEL VERIFICATION ITEMS

Preload correlation: Confirm torque-to-preload relationship and relaxation behavior
Pull-out stroke: Verify at least 3 mm nut clearance after release
Shear isolation: Demonstrate axial load path and cup-cone alignment
Command timing: Bound release duration across voltage, preload, and temperature
Thermal compatibility: Check preload and clearances across hot/cold extremes
Reset log review: Confirm remaining reset-life margin before flight integration
Final deployment test: Verify release with flight-like harness, springs, and kinematics

Table IV summarizes the system-level verification items that turn the component qualification into a flight-application qualification. These items are not unique to the mD3RN; they are common to release nuts and non-pyrotechnic HDRMs. The difference is that a resettable actuator makes it practical to perform these checks multiple times on representative hardware. This can reduce risk during SmallSat integration, where deployable-system behavior is often discovered late because the cost of repeated release tests is high for one-shot mechanisms.

The qualification data also indicate where mission-specific margins should be added. For low-to-moderate preload applications, reset testing can be extensive and still remain within the demonstrated life envelope. For applications near the top of the preload range, the number of full-load releases should be controlled tightly and allocated across qualification, acceptance, and flight-readiness tests. A project may therefore use dedicated engineering units for development testing, maintain a flight-unit reset budget, and reserve the redundant circuit for contingency or final mission use, depending on the reliability philosophy of the mission.

Another practical consideration is documentation. Because the mD3RN can be reset rapidly, it is easy for a program to perform informal release tests without preserving the context needed to interpret them. A reset record should be treated as part of the hardware history, similar to a thermal-cycle count or nonconformance log. The record should include the unit serial number, test configuration, preload, actuation circuit, voltage, command duration, estimated actuator temperature, number of resets, pull-check result, isolation-check result, and any observations during nut insertion. This information allows the final flight configuration to be compared directly with the qualification envelope summarized in this paper.

Finally, the mD3RN qualification campaign demonstrates a broader principle for SmallSat mechanisms: reusability changes the economics of verification. A mechanism that can be reset allows teams to test earlier, test more often, and test at a more representative level of assembly. The value is not only that the actuator survives a set of environmental loads, but that it enables the deployment subsystem to be exercised repeatedly before flight. This can reduce integration uncertainty for deployable antennas, solar arrays, payload covers, and other mechanisms whose real reliability depends on system-level kinematics as well as component-level strength.

X. LIMITATIONS AND FUTURE WORK

The campaign summarized here qualifies the actuator against a defined set of component-level environments and laboratory reset conditions. It should not be interpreted as a universal qualification for every spacecraft interface. Mission-specific loads, preload levels, thermal gradients, release direction, mounting stiffness, and deployment dynamics may differ from the test configurations. For this reason, the mD3RN should be treated as a qualified building block whose application envelope must be mapped to the spacecraft design rather than as a complete deployment subsystem by itself.

The most valuable extension of the present data set would be a larger statistical actuation-time matrix. The current product data defines the main trend with temperature at 24 V and 9 kN preload, but spacecraft integrators would benefit from quantified release-time distributions over voltage, preload, and temperature. Such a matrix would allow teams to select command durations using explicit probability and margin rather than bounding estimates. It would also support autonomous retry logic in spacecraft software, where the goal is to maximize release reliability while preventing unnecessary thermal exposure of the SMA element.

A second useful extension is the correlation between component-level reset testing and integrated deployment testing. The reset-cycle data are preload dependent and were generated under laboratory atmospheric conditions. Flight applications may expose the mechanism to vacuum, thermal gradients, contamination constraints, and different reset histories. Testing a representative deployable panel or antenna with the flight preload stack through vibration, TVAC, and repeated functional releases would provide direct evidence of how the component-level margins translate to subsystem-level margins.

Finally, future reporting should separate the emitted shock of the release event from the shock survival environment. The present paper focuses on environmental shock survivability under an externally generated SRS profile and on the actuator architecture as a low-shock, non-pyrotechnic release solution. For payloads with stringent jitter or optical-alignment requirements, direct measurement of the release-induced shock at spacecraft interface points would provide additional data for system-level shock budgets. This is particularly relevant for SmallSat missions that carry precise optical payloads.

XI. CONCLUSION

The mD3RN qualification campaign demonstrates that a compact, resettable, SMA-based release nut can satisfy the key environmental and operational needs of SmallSat HDRM applications. The mD3RN configuration combines a 225 g mass, dual actuation circuits, 24-32 V command compatibility, operation from -65 deg C to +75 deg C, a nominal 15 kN axial preload rating, and high-preload life-cycle demonstration up to 18 kN. Vibration testing subjected six units to resonance surveys, 24 g sine vibration, and 30.66 grms random vibration across all axes. Shock testing subjected the mD3RN set to a 50 g to 1500 g SRS environment. TVAC testing completed ten hot/cold cycles under high vacuum with no NCRs. Reset cycling quantified the preload-dependent actuation life, demonstrating more than 100 successful actuations at 6 kN, 88 at 10 kN and 15 at 14kN under laboratory conditions.

The qualification evidence supports the use of the mD3RN where resettable ground testing, low-emitted release shock, compact packaging, and high axial preload capability are valuable. Mission-specific adoption should still verify preload stability, separation stroke, shear isolation, command timing, and reset budget at spacecraft level. Future work should expand the statistical actuation-time data set over voltage, preload, and temperature and correlate component-level qualification data with deployment telemetry from flight missions.

REFERENCES

[1] Dcubed, “D3-1-17-TDS-mD3RN-AL-Datasheet-2026_H1: Datasheet, Milli Release Nut mD3RN,” 4 Mar. 2026.

[2] Dcubed, “D3-1-17-1-UM-mD3RN-AL-UserManual-2026_H1: User Manual, Milli Release Nut mD3RN (1-17-1),” 13 Mar. 2026.

[3] ZARM-FAB, “Qualification Test Report FAB-QTR 306013, Sine and Random Vibration, Milli Release Nuts mD3RN and Micro Pin Puller uD3PP,” 2 Feb. 2026.

[4] KRP Mechatec, “0497-RD-TR-0001, Test Report - Shock Test of DCUBED Actuators,” Issue A, 5 Feb. 2026.

[5] KRP Mechatec, “0497-RD-MM-0004, PTR for TVC Test,” Issue A, 3 Feb. 2026.

[6] Dcubed, “D3-1-17-RP-Reset cycles test,” Technical Note, Version 1D1, 2 Mar. 2026.