Six-foot free-drop screening

Swept/tied assembly · nominal flat impact

Abaqus/Explicit 2026 HF5 · Preliminary customer report · Revision D0

1. Executive assessment

The nominal, zero-roll/zero-pitch drop simulation completed the prescribed 2 ms impact step. It provides a preliminary picture of load transmission from the four housing feet into the cover, window and PCB. **It does not yet provide a qualified damage, survival, or acceptance prediction.** No acceptance criteria, calibrated failure laws, or material allowables were supplied.

Primary qualification issue. Artificial strain energy reaches 8.41 J. At the end it is 52.7% of total internal energy. The small energy-balance drift therefore cannot, by itself, establish accuracy. Local acceleration histories also contain very large, unresolved high-frequency peaks.

The modeled mass is 3.4935 kg and the initial kinetic energy is 62.65 J. The initial downward speed is 5.989 m/s, representing a 1.8288 m free drop with a 0.05 mm starting clearance above a rigid floor. First nontrivial floor reaction appears at approximately 0.009 ms. The recorded peak normal force is 681.7 kN at 0.043 ms.

Response indicator	Sampled maximum	Interpretation
Housing von Mises stress	2,311 MPa	Impact-foot concentration; elastic screening only.
Cover von Mises stress	1,001 MPa	Roof/aperture region near the window.
Window maximum principal stress	318 MPa	Fastener-hole neighborhood; no cracking model.
PCB maximum principal stress	312 MPa	Mounting-hole neighborhood; isotropic FR4 surrogate.
Window relative center motion	−2.450 mm	Relative to its attachment displacement plane.
PCB relative center motion	−1.044 mm	Relative to its attachment displacement plane.

The window reaches approximately 8.53% maximum principal logarithmic strain, and the PCB reaches 1.52%. These large calculated responses make material calibration, joint representation and numerical sensitivity studies priorities. Stress values must not be converted directly into a factor of safety or a claim of component failure.

This report covers only `drop_swept_tied_roll_p0_pitch_p0.odb`. It contains no results from other orientations or another mesh route. The supplied run was postprocessed in read-only mode; no new simulation was submitted.

2. Simulation definition

The model retains a stainless-steel housing and cover, a PMMA window and a solid FR4 PCB. Small markings, selected blends/chamfers, a seal groove and a shallow cover pocket were removed during preparation. Functional apertures, impact feet and attachment locations were retained. The companion analyst deck documents those operations in detail.

Part	Density (kg/m^3)	Young's modulus (MPa)	Poisson ratio
Housing / cover	8,000	193,000	0.29
PMMA window	1,180	3,000	0.35
Solid FR4 PCB	1,850	20,000	0.14

All materials use isotropic linear elasticity with geometric nonlinearity. These are assumed screening properties, not calibrated material cards. There is no plasticity, rate dependence, fracture, delamination, or element deletion. The PCB excludes electronic component and stackup detail.

The assembly contains 86,339 C3D8R solid elements, 18 deformable B31 bolt shanks, and 1,356 beam spokes belonging to 36 rigid spiders. The PCB has four elements through its 5 mm thickness; the window has three through its 3.175 mm thickness. The nominal in-plane panel and cover size is 1.5 mm; the housing size is 2 mm. Enhanced hourglass control is specified for the solids.

Three internal housing planes at Z = 7.4, 17.4 and 60 mm use node-to-surface tied constraints, with 3,859 secondary nodes in total. Each physical part remains separate. The 18 retained joints use nominal 4 mm shanks between rigidly coupled bore walls. Retained hardware mass is represented; preload, threads and detailed bearing compliance are absent. Four external bottom mounting bolts are omitted from the free-drop assembly.

The fixed rigid ground contacts the physical part skins. General contact includes the six interpart pairs and four part-to-ground pairs, using hard normal behavior and zero friction. Hardware contact and self-contact are not included. No gasket is modeled. Gravity is 9,806.65 mm/s^2 downward. The analysis uses mm, s, tonne, N and MPa consistently.

The impact step lasts 0.002 s, with an explicit increment scale factor of 0.8 and bulk-viscosity coefficients 0.06 and 1.2. No mass scaling is specified. Requested history spacing is 1 µs; requested field spacing is 20 µs. The actual output times, rather than idealized indices, are used in the calculations below.

> Scope: this is the nominal flat orientation only. No robustness claim is made for small angular offsets, other drop orientations, repeated impacts, or handling conditions.

3. Numerical qualification

The status file reports successful completion after 48,176 increments. Reported stable increments during the step are approximately 4.15×10^{-8} s. The run used the double-precision package and Explicit executables with 16 domains. Successful completion establishes that the solver advanced to the requested time; it does not establish mesh convergence or physical validity.

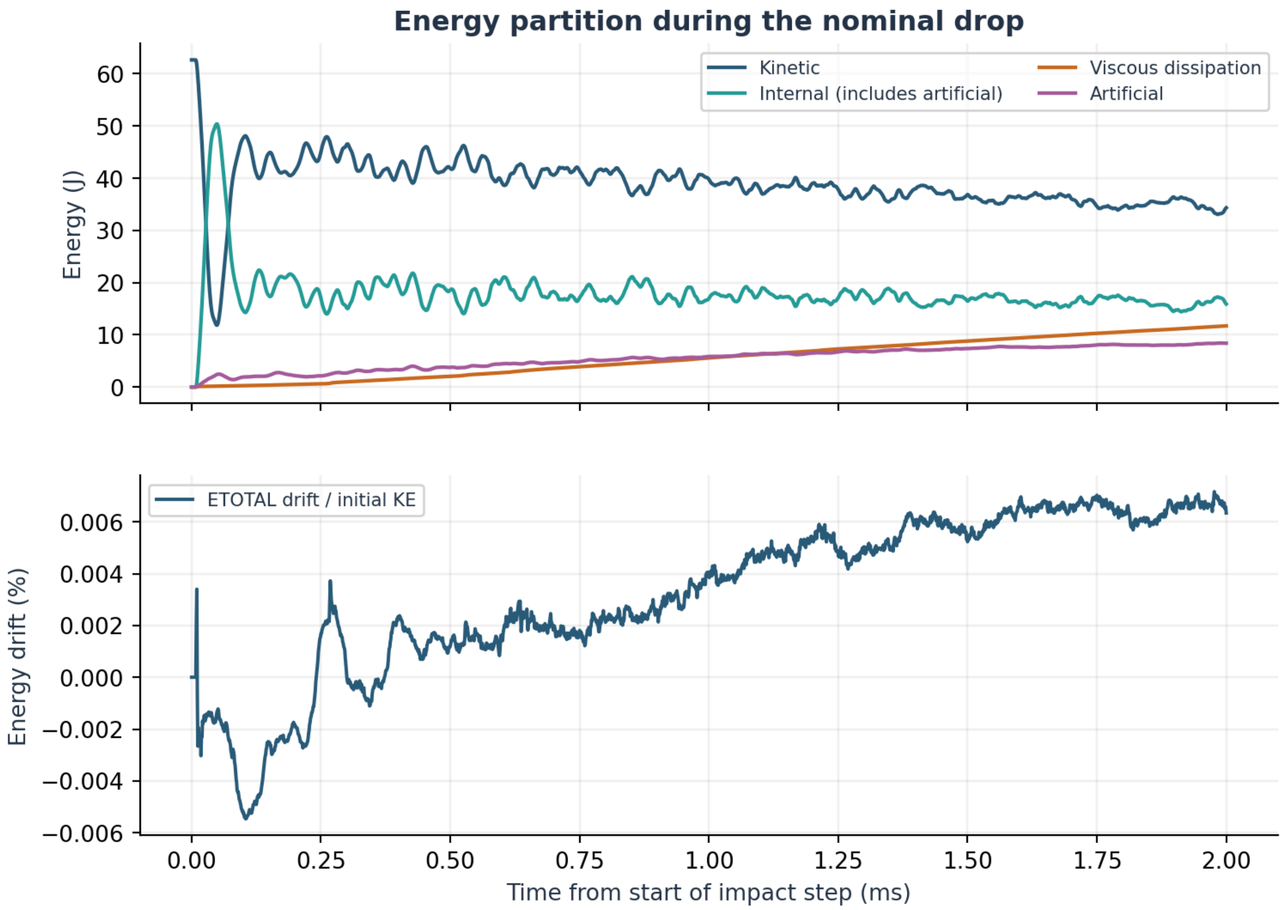

Figure 1: Whole-model energies and normalized energy-balance drift. ALLIE already includes ALLAE; the plotted artificial energy must not be added to internal energy again. Energy units are converted from N·mm to J.

The maximum absolute ETOTAL drift is 0.0072% of initial kinetic energy. Peak internal energy is 50.39 J at 0.049 ms. Artificial energy is approximately 4.79% of internal energy at that instant, but its relative contribution grows during the later response: it reaches 55.9% when evaluated after internal energy first exceeds 1% of initial kinetic energy, and ends at 52.7%.

At 2 ms, kinetic, internal and viscous energies are 34.32, 15.9 and 11.71 J, respectively. The final artificial energy is 8.38 J, or 13.38% of initial kinetic energy. Viscous dissipation is 18.68% of initial kinetic energy. Artificial energy is a numerical contribution; the viscous term should not be interpreted as experimentally calibrated material damping in this model. The requested output does not localize these contributions by part or element.

The definitions of ALLIE, ALLAE and ETOTAL follow the Abaqus energy-output documentation. The control formulation follows the Abaqus section-controls documentation.

4. Impact force and rebound

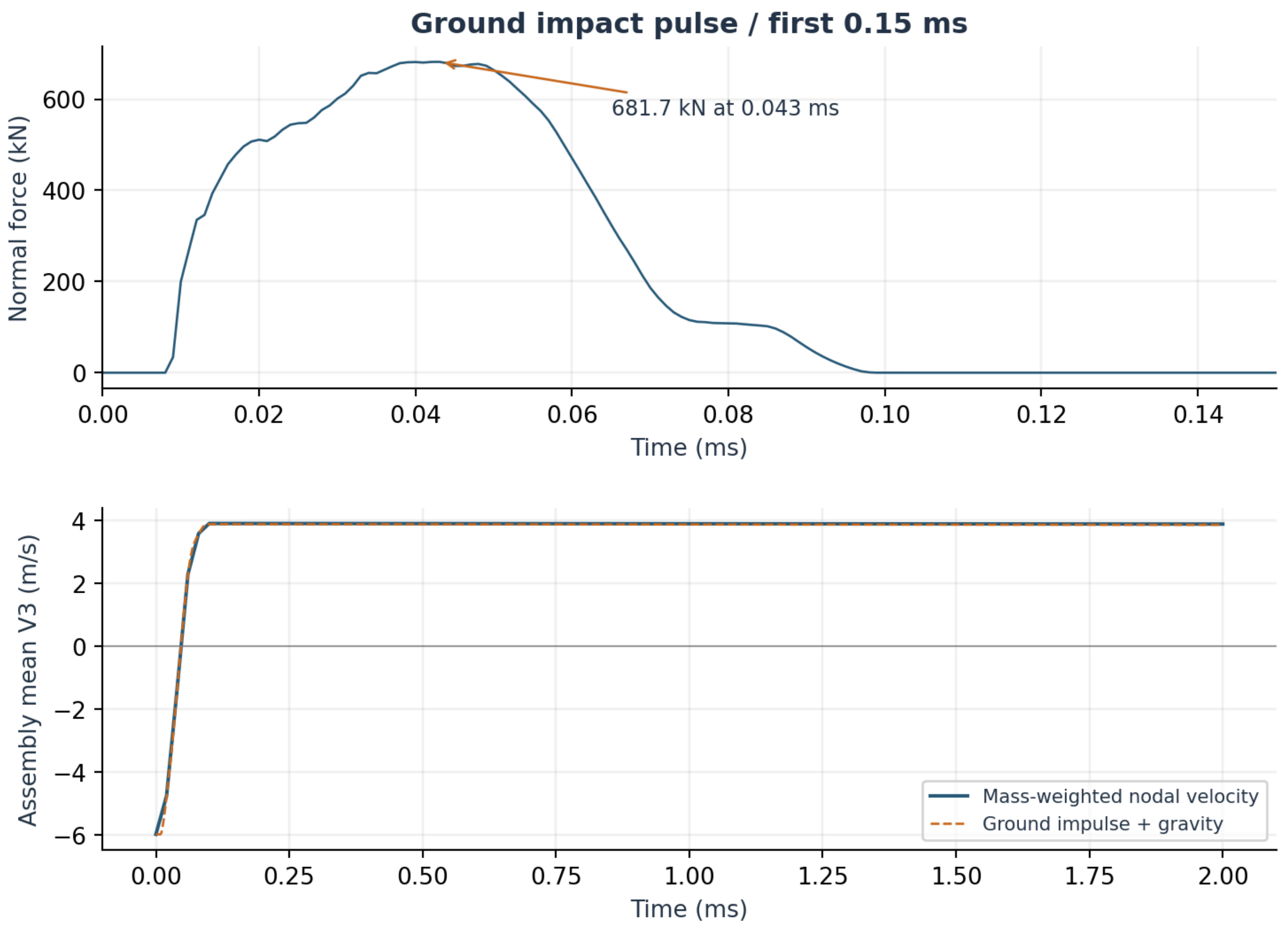

Figure 2: Normal ground reaction from the 1 μs history request, and assembly mean vertical velocity. The second velocity curve is reconstructed from ground impulse and gravity. Upward velocity is positive.

The peak ground force is 681.7 kN at 0.043 ms. The integrated upward ground impulse is 34.462 N·s over the recorded 2 ms interval. The mass-weighted assembly mean vertical velocity is 3.881 m/s upward at the end, and the final recorded ground force is zero. This indicates separation from the floor at the end of the recorded interval; it does not establish the absence of later reimpact.

The velocity cross-check uses initial solid masses distributed to their eight nodes and beam masses distributed to their ends. This is a postprocessing approximation to the model's mean translational velocity. Its largest discrepancy from the impulse reconstruction is 0.42% of the initial speed. The check supports force sign, mass and unit consistency, but is not an independent validation of local stresses or of the mass-lumping details.

At the field frame near 0.040 ms, the four foot-set normal forces are approximately 167.5, 167.6, 168.6 and 177.7 kN (sets NS211–214, respectively). Their sum is approximately 681.3 kN. This near-even sharing is consistent with the nominal flat impact; the modest asymmetry reflects the actual assembly and mesh. This field frame is slightly earlier than the history-force maximum and should not be treated as its exact decomposition.

The maximum sampled nodal contact pressure is 2692.2 MPa at 0.04 ms, at node 62960 on an impact foot. Contact pressure is a local penalty-contact result and is especially sensitive to local mesh, stiffness and material representation.

5. Panel motion and local shock response

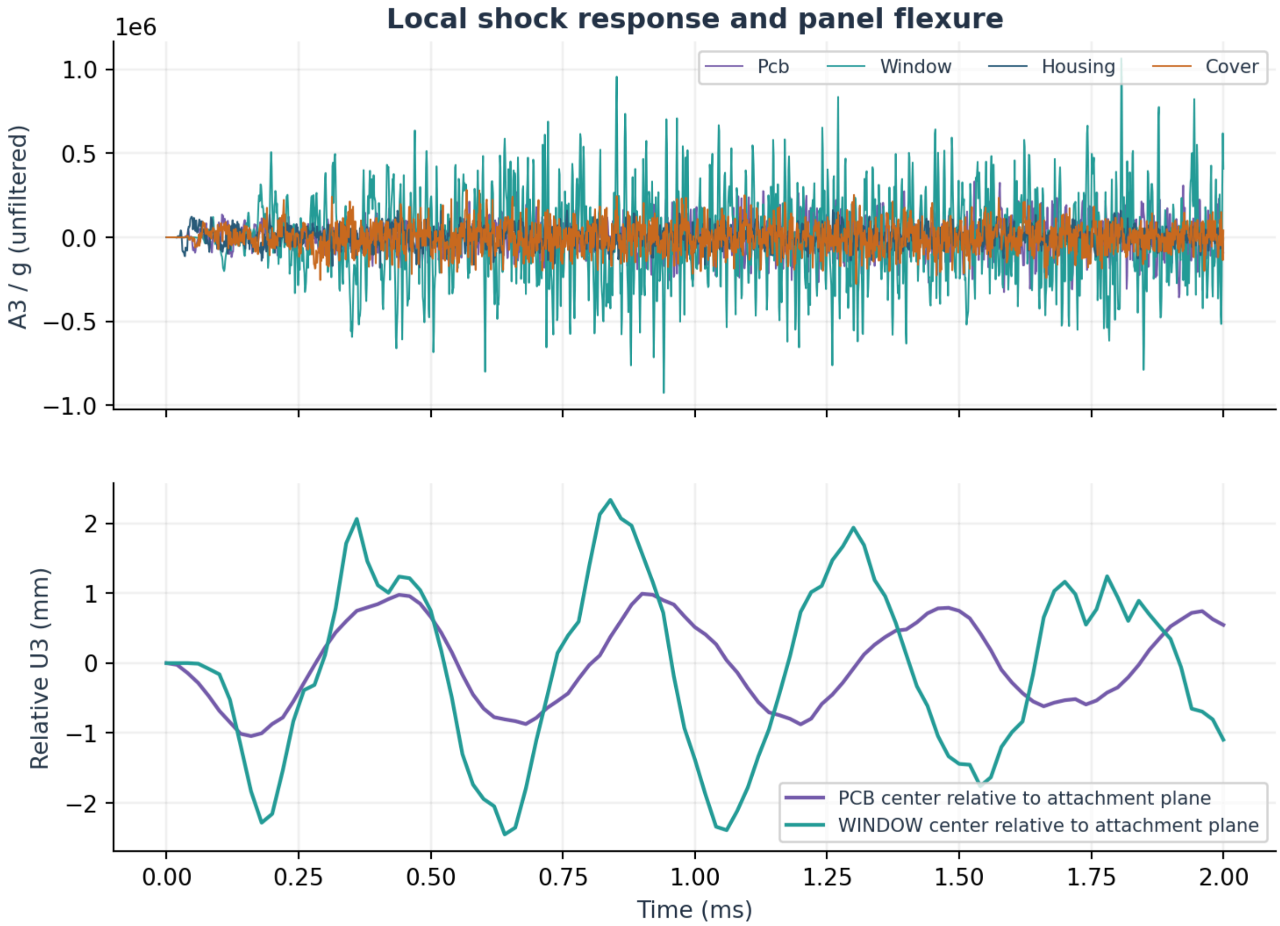

Figure 3: Unfiltered vertical accelerations at the four monitor nodes, followed by PCB and window center motion relative to their attachment displacement planes. Acceleration is divided by 9,806.65 mm/s^2.

The PCB center's largest sampled relative displacement is −1.044 mm at 0.16 ms. The window reaches −2.45 mm at 0.64 ms. Negative values indicate motion downward relative to the attached boundary reference. Absolute displacement is dominated later by assembly rebound, so it is not used alone as a panel-flexure measure.

For each panel, the reference is a least-squares plane fitted to the vertical displacements of its attachment hubs, evaluated at the monitor's original X–Y position. This removes translation and the linear small-rotation contribution; it is not a full finite-rotation co-moving strain measure. These values use the 20 µs field frames and are sampled extrema, not guaranteed time-continuous peaks.

The largest absolute raw A3 histories are approximately 358,000 g at the PCB monitor, 1,066,000 g at the window, 182,000 g at the housing base and 283,000 g at the cover. These are pointwise, unfiltered numerical outputs. They are **not qualified equipment shock loads**. Contact/constraint transients, high-frequency local modes, stabilization and sampling/aliasing all require examination before selecting an agreed sensor location, bandwidth and filter for comparison with a shock requirement. No unrequested filtering has been applied to conceal these peaks.

6. Housing response

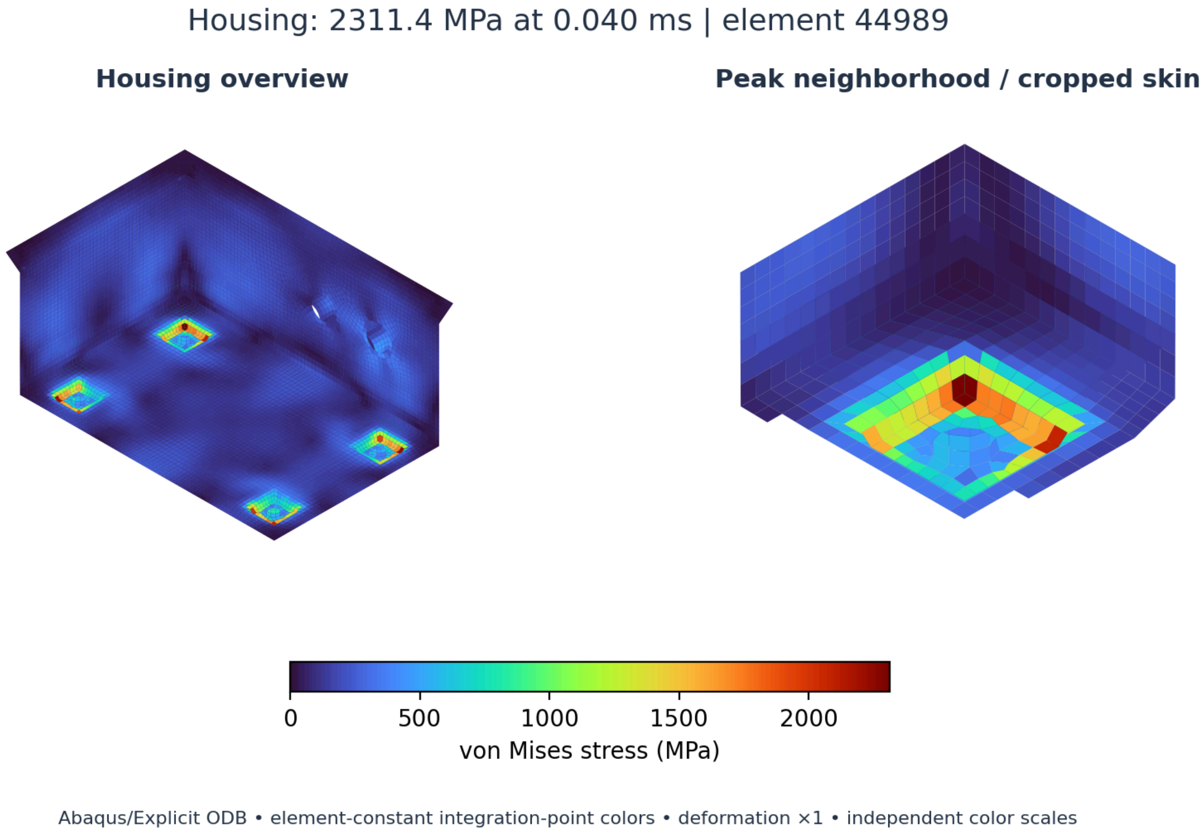

Figure 4: Housing von Mises stress at the frame containing its sampled maximum. The underside view exposes the impact feet. The detail is a cropped exterior mesh neighborhood, not a physical cut.

The housing reaches a maximum von Mises stress of 2,311.4 MPa at 0.040 ms in element 44989, with initial centroid approximately (137.399, 86.608, −2.144) mm. This places the maximum in an impact foot near the contact/load-introduction region. The minimum principal stress at that same element and frame is −2,900.8 MPa; its compressive logarithmic principal strain is approximately −1.33%.

The maximum tensile principal stress occurs elsewhere: 836.5 MPa in element 61218 at approximately (113.474, 73.706, 8.400) mm, also at 0.040 ms. The distinct tensile and equivalent-stress locations should be retained when planning local refinement or material updates.

The housing's measured minimum Cubit scaled Jacobian is 0.1577, with 16 housing elements below 0.2. The Abaqus input processor flags 132 distorted elements across the complete model using different criteria. No nonpositive initial Jacobians were identified in the preparation audit. Positive element volumes and solver completion do not demonstrate convergence of the sharp foot/contact stress concentration.

The feet were reunited with the floor before meshing, so no internal tied interface crosses an impact foot or its root. Nevertheless, removed blends and chamfers alter local stiffness and notch geometry. The present housing peak is best used to identify a refinement/material-calibration region. A plasticity model and mesh/formulation sensitivity study are needed before interpreting residual deformation or a physical stress limit.

7. Cover response

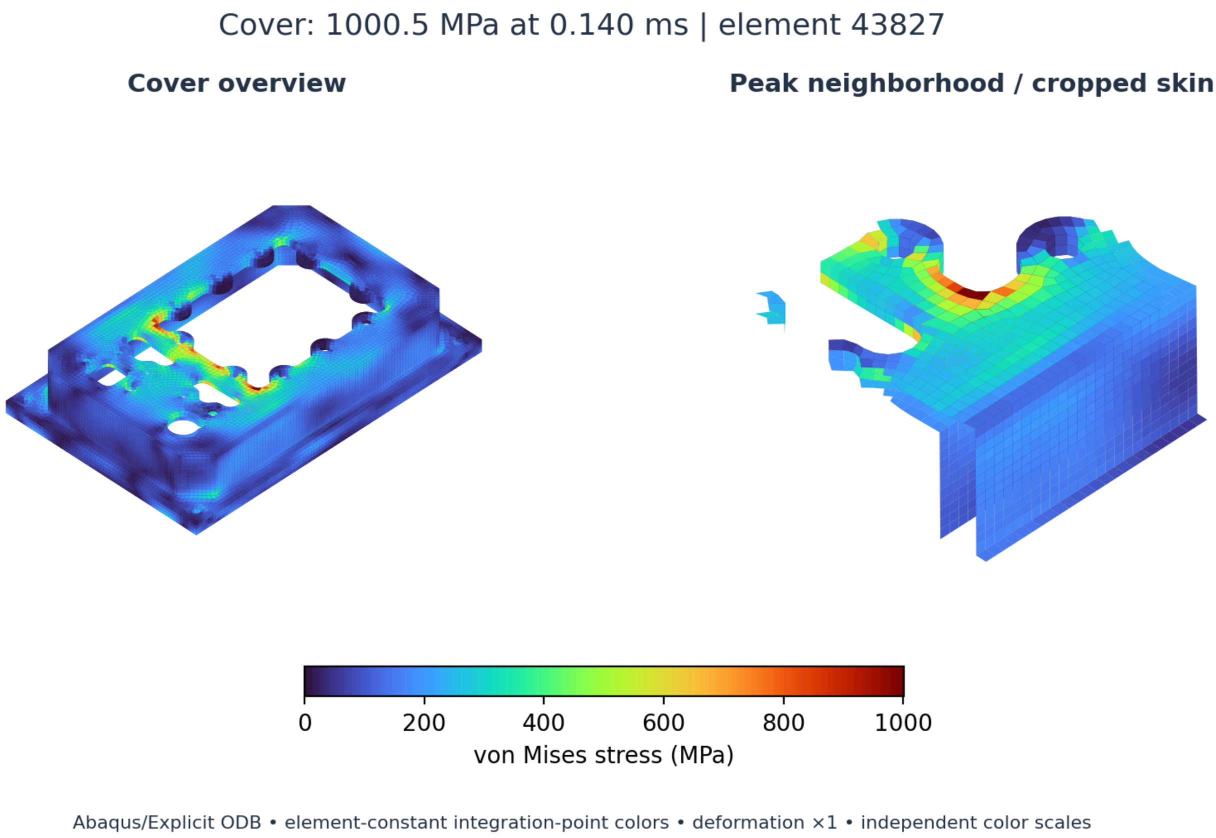

Figure 5: Cover von Mises stress at 0.140 ms. The color scale is independent of the housing figure.

The cover's maximum sampled von Mises stress is 1,000.5 MPa in element 43827 at 0.140 ms. Its initial centroid is approximately (96.164, 78.516, 94.300) mm, near the window aperture/attachment region of the roof. The same element and frame carry the maximum tensile principal stress, 898.1 MPa.

Maximum tensile logarithmic principal strain is approximately 0.477%. The minimum principal stress is −892.6 MPa in element 43891 at 0.160 ms, with centroid near (96.880, 57.839, 94.300) mm. These locations show that the cover response is concentrated around roof openings and attachment load paths, rather than being described by one uniform stress state.

The cover uses a three-region conforming solid mesh across flange, wall and roof. Its minimum initial scaled Jacobian is approximately 0.512. Selected roof, flange and edge features were simplified to enable sweeping. These simplifications and the rigid bore couplings can change local peak stresses even when global part motion is adequately represented.

The cover and housing use the same assumed elastic steel properties. No yielding, residual deformation, bolt slip or preload relaxation is available from this run. The calculated roof stress should therefore guide a targeted follow-up model rather than a direct acceptance decision.

8. Window response

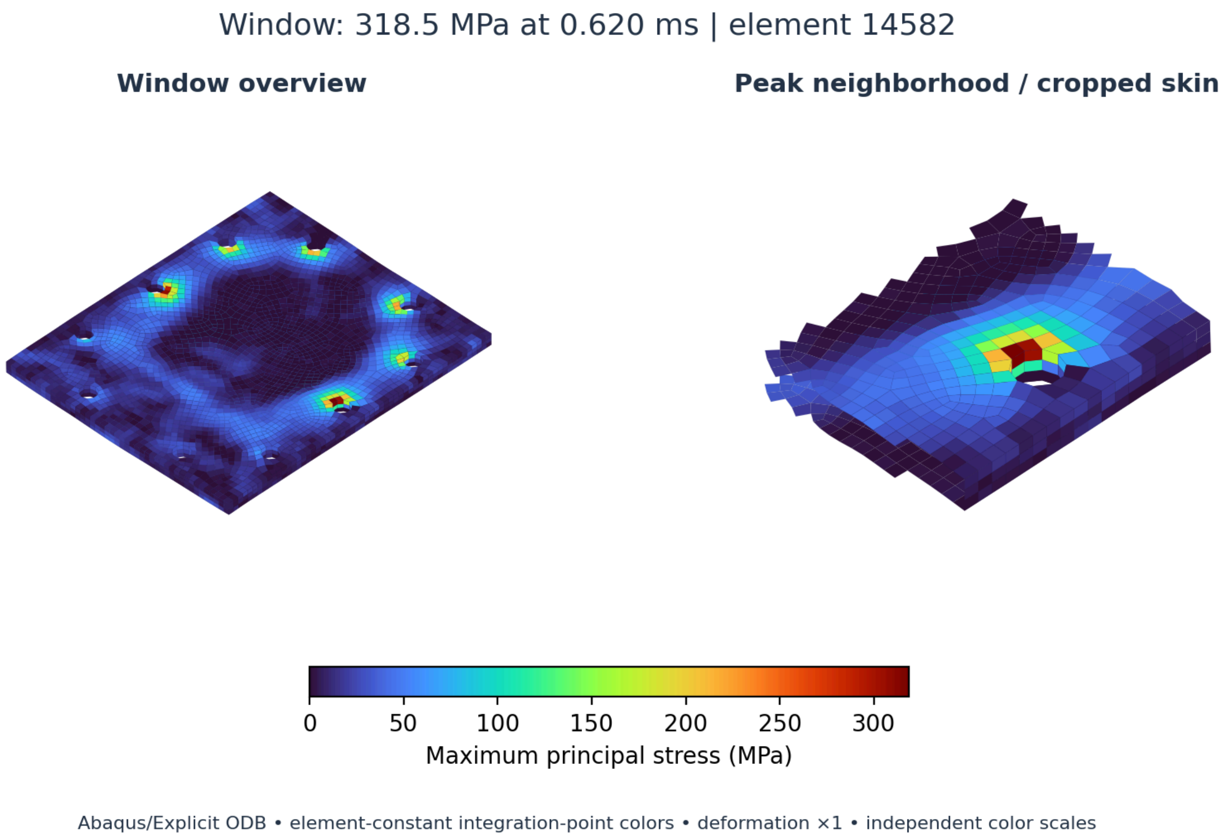

Figure 6: PMMA maximum principal stress at 0.620 ms. Positive tension is shown with a color range beginning at zero; compressive values fall below the displayed range. No nodal stress averaging is applied.

The maximum sampled tensile principal stress is 318.5 MPa in element 14582 at 0.620 ms. Its initial centroid is approximately (61.178, 76.580, 91.521) mm, close to the upper-center attachment-hole neighborhood. The maximum von Mises stress is 237.8 MPa in the same element and frame. The minimum principal stress is −220.2 MPa in element 20108 near the opposing attachment region.

The maximum tensile logarithmic principal strain is 0.08535 (8.53%), and the minimum is −0.05694 (−5.69%). Together with approximately 2.45 mm relative center motion, this is a large-deformation response for the assumed 3.175 mm thick window. Geometric nonlinearity is enabled, but the constitutive model remains linear elastic and has no polymer rate dependence, crazing or fracture law.

The local stress field is strongly affected by rigid coupling of the bore walls and by the assumed bolt/contact model. A detailed clamped region, contact/friction/preload characterization, and a calibrated polymer material/failure law are priorities. The figure locates regions for investigation; it does not establish whether, where, or when the actual window cracks.

9. PCB response and panel deformation

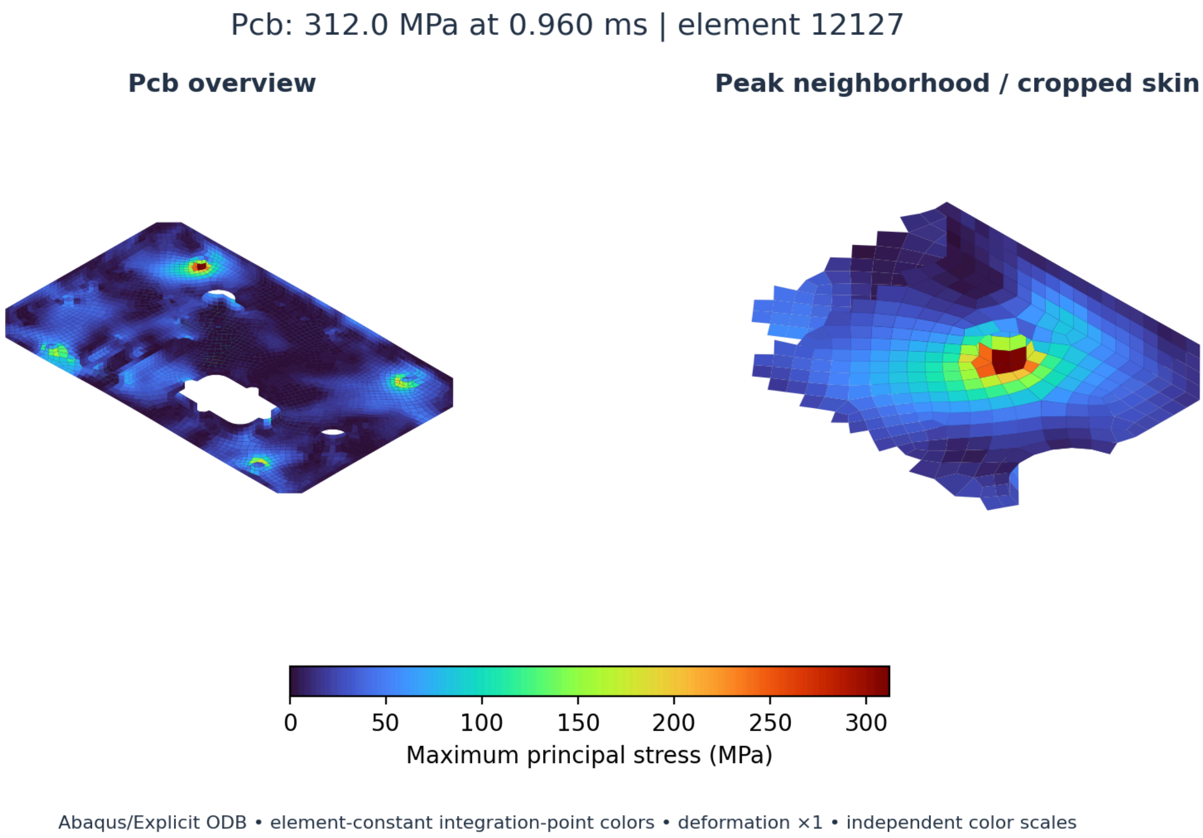

Figure 7: Solid-FR4 maximum principal stress at 0.960 ms, viewed from below. The cropped detail exposes the attachment neighborhood containing the tensile maximum.

The PCB reaches a sampled maximum von Mises stress of 293.9 MPa in element 12126 at 0.960 ms. Its centroid is approximately (36.860, 21.767, 18.025) mm, near a mounting hole. Maximum tensile principal stress is 312.0 MPa in adjacent element 12127, at approximately (36.252, 22.805, 18.025) mm. Maximum tensile logarithmic principal strain is 1.52%.

The PCB was intentionally modeled as a homogeneous isotropic solid FR4 plate, as requested. Consequently, the run does not represent laminate directionality, copper layers, component inertia, solder joints, delamination, or board-level failure criteria. The straightened countersinks and rigid bore spiders also suppress actual bearing/ contact compliance. The predicted mounting-hole peaks are therefore sensitive to idealization.

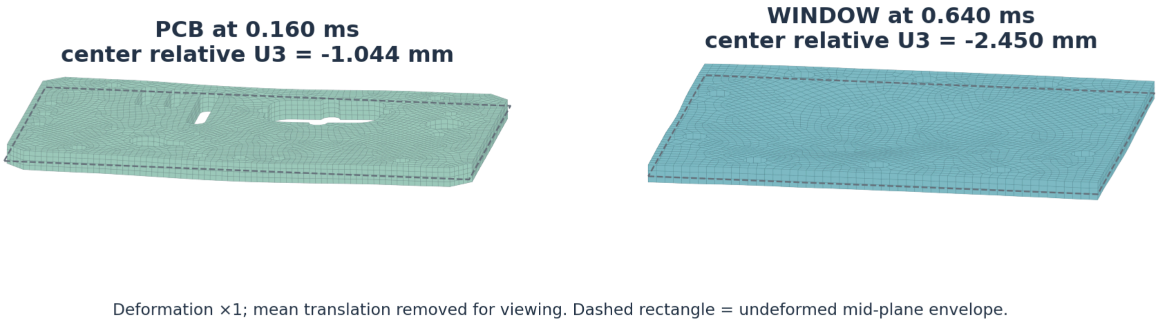

Figure 8: Panel shapes at the frames of maximum sampled relative center displacement. Deformation scale is one; mean translation is removed only for viewing.

10. Joint loads and stress evolution

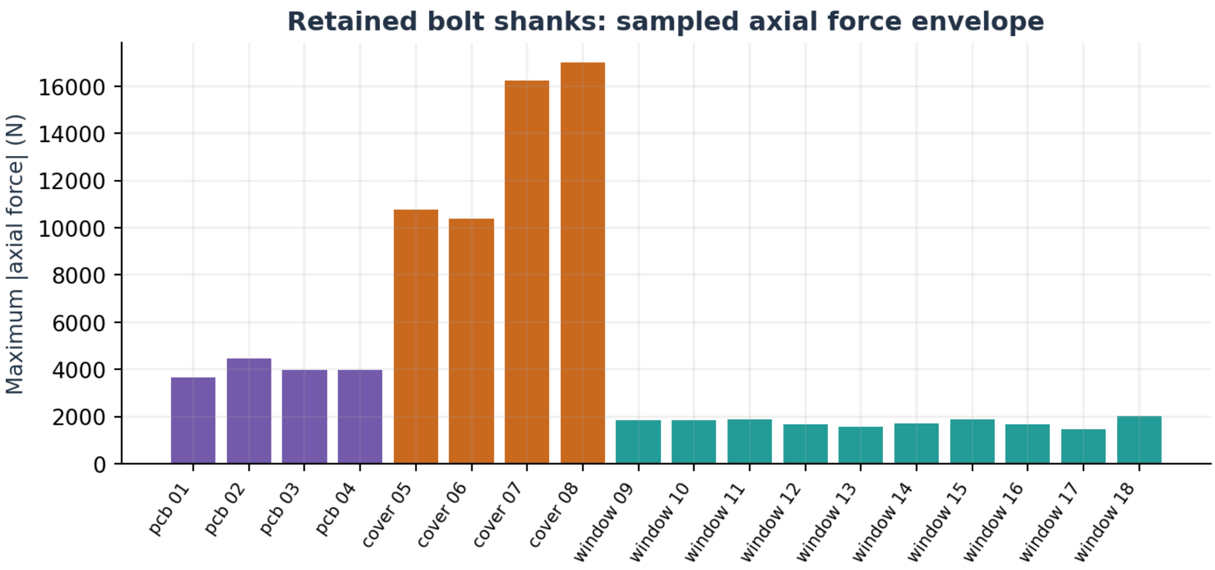

Figure 9: Envelope of absolute sampled B31 axial force for each retained joint. Joint names follow `connections.json`; numbering is global across the 18 joints.

The largest sampled absolute axial shank force is 16.99 kN in `cover_08`, element 87003, at 0.22 ms. This is a beam resultant, not a fastener capacity assessment. The model contains no calibrated bolt grade, preload, thread engagement, pull-through or failure criterion.

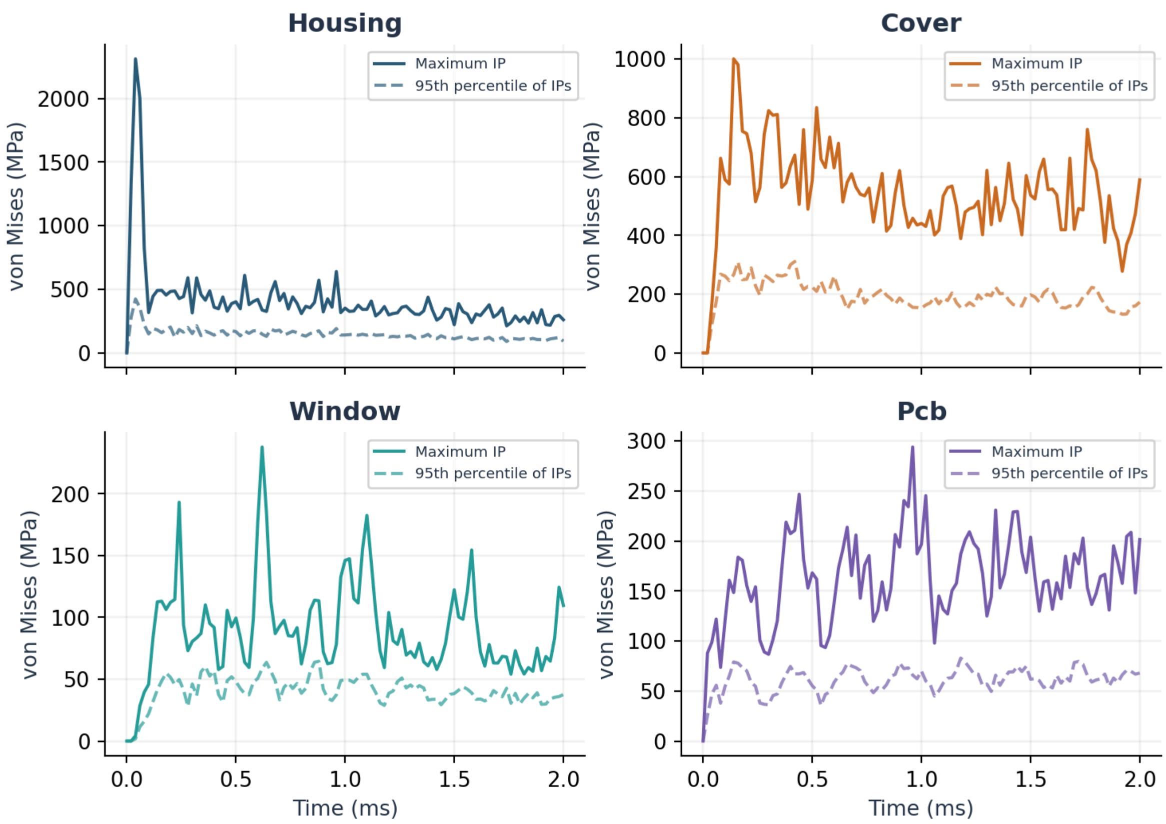

Figure 10: Maximum and unweighted 95th-percentile integration-point von Mises stress by part. The percentile is spatial at each saved frame, not a confidence interval or a convergence estimate.

The housing responds first at the impact feet; the cover reaches its largest sampled equivalent stress at 0.140 ms, followed by the window at 0.620 ms and the PCB at 0.960 ms. The gap between each part's maximum and 95th percentile emphasizes localization. Refinement should target the identified load paths while also checking global motion and energy partition.

11. Limitations and prioritized follow-up

1. Resolve numerical sensitivity before customer acceptance. Request part/element artificial and viscous energies (for example, ELASE/EASEDEN where supported), examine deformed element patterns, and compare local refinement and suitable element/hourglass formulations. The large final ALLAE contribution must be understood rather than inferred to be harmless from the ETOTAL balance. Preserve energy, momentum and mass checks in every comparison.

2. Check contact and ties dynamically. All 3,859 requested secondary nodes are reported tied during input processing. Initial interface interpolation checks found zero gap to numerical tolerance and no missed secondary nodes. Those are initialization checks, not evidence that dynamic stress transfer is insensitive to the three cuts. Abaqus flags 1,364 nodes in `WarnNodePerimTieSeam`: tied surfaces retain a seam in contact topology. Compare a locally conforming region where practical, inspect contact near tie perimeters, and assess contact-penalty sensitivity. The smallest valid sampled general-contact opening is −0.00474 mm; undefined extreme-float sentinel values are excluded. This is an aggregate gap diagnostic, not a pair-specific penetration assessment.

3. Calibrate material response. Use appropriate steel plasticity/rate data, a PMMA material and fracture description relevant to the environment and rate, and a PCB representation consistent with the intended failure question. Determine whether isotropic FR4 is sufficient for global motion; it cannot establish laminate or component failure. Obtain traceable material allowables before reporting margins.

4. Improve joint and interface realism. Establish bolt grade/diameter, grip, preload, friction and contact compliance. Compare rigid bore spiders with an appropriate distributing or detailed bearing representation. Confirm the service role of the omitted seal groove, gasket and shallow cover slot. Retained hardware mass is matched, but inertia/compliance are not fully calibrated by mass matching alone.

5. Establish convergence and measurement definitions. Refine foot roots, apertures and panel attachments. Agree on stress extraction locations, meaningful spatial averaging, shock bandwidth and sensor orientation. Save selected histories/fields at adequate rates to resolve relevant peaks without aliasing. A single mesh and one output interval do not demonstrate convergence.

6. Extend physical coverage. Continue long enough to assess later vibration, contact and potential reimpact; the model retains 34.3 J of kinetic energy at 2 ms and significant panel motion. Evaluate the required orientation envelope and repeatability, incorporate omitted component masses, and correlate to instrumented drop tests before issuing a survival conclusion.

Current disposition: retain this run as a reproducible baseline for model development. No pass/fail determination, damage map or customer release recommendation is supported at this stage.

12. Traceability and postprocessing method

The source run is in `abaqus_explicit/swept_tied/` beneath `find_replace_prepare_rom_bolts_codex_test`. The output database is `drop_swept_tied_roll_p0_pitch_p0.odb` (1,893,482,380 bytes). Its full SHA-256 and those of the input, logs, CAD and preparation sources are recorded in `data/provenance.json`. The current `mesh.inc` hash matches the preparation manifest. This establishes consistency of the present files; input hashes were not embedded in the ODB at run submission.

The ODB identifies Abaqus/Explicit 2026 HF5 and contains 101 frames in step `IMPACT`, ending at approximately 0.002 s. The status file independently confirms successful completion. The reported extrema use all saved frames and all relevant integration-point values, without nodal extrapolation or stress averaging. Contour images map each C3D8R element's integration-point scalar uniformly onto its exposed faces. This makes the pictures traceable to the numerical extrema but does not interpolate a smooth physical stress field. Deformation scales and cropped views are explicitly labeled.

Monitor	Node label	Initial coordinates (mm)
PCB / NS401	7333	(76.033, 50.711, 21.150)
Window / NS402	25513	(61.018, 50.723, 89.933)
Housing base / NS403	69075	(76.200, 49.816, 2.469)
Cover / NS404	58095	(110.324, 51.587, 93.550)

Ground force comes from the fixed ground reference node's RF3 history. Positive reaction balances downward contact on the rigid plane; its magnitude is the upward force acting on the assembly. Impulse uses trapezoidal integration at actual history times. Stress and beam-force extrema come from the 20 μs field output; acceleration extrema come from the 1 μs monitor histories. Neither sampling interval guarantees capture of every true temporal maximum.

The review package includes the editable Typst source, compiled PDF, editable PowerPoint, slide PDF, operation index, extracted JSON/CSV data, figures, and reproduction scripts. `extract_results.py` and `extract_contact.py` use Abaqus Python to open the ODB read-only. `analyze_results.py` and `render_results.py` produce metrics and figures. No script in this package submits an analysis job.

The analyst deck uses independent offscreen Cubit reconstruction from the accepted CAD/journals, with highlighted before/after images and actual webcut previews. Its operation index is separate from this high-level simulation report.

Technical references used for interpretation are the linked Abaqus energy-variable definitions, section controls, and surface-based tie constraints. These web references are the 2025 documentation; the solver version and run diagnostics above come directly from the installed 2026 HF5 output.