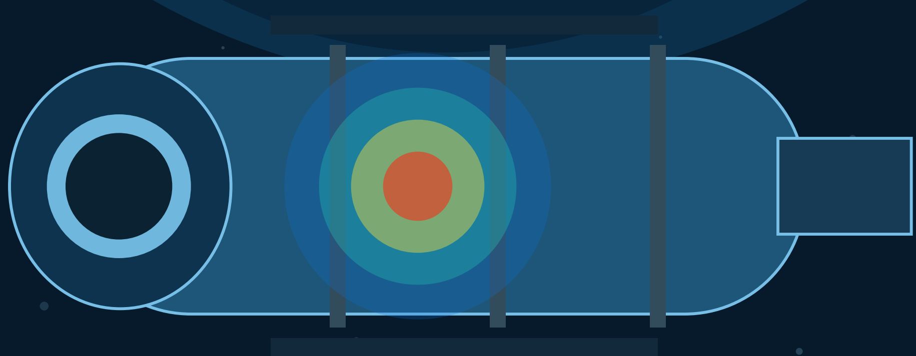
STELLA NOVA
EDUCATION

Submersible Structural Depth & Implosion Visualizer

Analytical screening methodology, governing equations, uncertainty model, and interpretive limitations

TECHNICAL METHODOLOGY NOTE - VERSION 1.0.0



Stella Nova Education & Research Center
July 2026

Purpose, scope, and safety boundary

The Submersible Structural Depth & Implosion Visualizer (SSDIV) is a browser-based educational and preliminary design-comparison instrument. It estimates the pressure at which one of several simplified limit states may control a pressure hull and converts that pressure into an equivalent seawater depth. It also visualizes where a controlling failure mode may initiate and presents a mode-specific mechanical collapse sequence.

Critical limitation. SSDIV is not a finite-element solver, classification review, design approval, proof test, material qualification, nondestructive inspection, or certification analysis. It must never be used as the sole basis for placing people in a pressure vessel or for selecting an operating depth.

Outputs are deliberately separated

Output	Interpretation
First-damage depth	Depth at which the selected model predicts initiation of a local damage or instability process.
Nominal collapse depth	Median or selected analytical collapse estimate before applying the user-selected operating safety factor.
Recommended operating depth	Nominal collapse estimate divided by the selected safety factor. It is still not an approved operating depth.
95% screening interval	Monte Carlo interval produced by varying geometry, material, joint, viewport, and imperfection inputs.
Dominant limit state	Lowest modeled pressure among shell buckling, material yield, viewport capacity, and joint/bond capacity.

Required real-world validation

Human-occupied submersibles require qualified engineering, applicable pressure-vessel and marine standards, validated nonlinear analysis, representative material testing, manufacturing quality assurance, full-scale hyperbaric proof testing, repeated pressure-cycle testing, nondestructive inspection, documented maintenance limits, independent review, and conservative operational governance.

Governing pressure and shell equations

The browser model begins with differential hydrostatic pressure. Density is user-controlled because seawater density varies with salinity, temperature, and pressure. The internal cabin pressure is subtracted from ambient pressure.

External differential pressure

$$P_e(h) = \rho_{sea}\, g\, h - P_{internal}$$

where ρ_{sea} is seawater density, g is 9.80665 m/s², h is depth, and $P_{internal}$ is cabin pressure.

Classical cylindrical shell buckling

For cylindrical and predominantly cylindrical hulls, SSDIV uses a classical thin-shell external-pressure relationship as a baseline. A preset-specific structural factor may represent ring stiffening or known geometric support, while a knockdown factor reduces the ideal result for ovality, initial imperfections, defects, analysis conservatism, and cycle degradation.

$$P_{cr,cyl} = K \cdot S \cdot [2E / \sqrt{(3(1-\nu^2))}] \cdot (t/R)^3$$

This relationship is highly sensitive to thickness and geometric imperfections. The ideal elastic value is not treated as a safe operating pressure.

Classical spherical shell buckling

$$P_{cr,sph} = K \cdot S \cdot [2E / \sqrt{(3(1-\nu^2))}] \cdot (t/R)^2$$

The spherical relationship differs in exponent and can produce substantially higher ideal elastic pressures than a similarly proportioned cylinder. Real openings, joints, seats, welds, local thinning, and imperfections can become controlling before ideal shell buckling.

Material-yield screening

For a cylindrical membrane approximation, SSDIV estimates $P_y \approx \sigma_y t/R$. A factor of two is used for a spherical membrane approximation. This is a screening relationship only and does not resolve local bending, discontinuity stresses, plasticity, residual stress, anisotropy, or fracture mechanics.

Additional limit states and uncertainty model

Viewport screening

Viewport capacity is approximated from a material-specific compressive-strength scale, the square of thickness-to-diameter ratio, and a seat/joint quality factor. It is not a substitute for ASME PVHO viewport design calculations, material lot testing, seat geometry analysis, or service-life inspection.

Joint and bond screening

Joint capacity is estimated as a fraction of membrane yield pressure modified by the selected joint type and quality. Adhesive-bonded interfaces receive a lower cap. The model does not resolve bolt preload, flange rotation, peel stress, bondline thickness, cure history, thermal mismatch, corrosion, or local fracture.

Geometric degradation

The nominal wall thickness is reduced by defect depth. Ovality and imperfection amplitudes reduce the ideal shell pressure through a continuous knockdown relationship. These user inputs are not automatically inferred from an STL because an exterior tessellation does not contain wall thickness, laminate architecture, hidden joints, bond quality, manufacturing defects, or material properties.

Pressure-cycle damage

A simplified nonlinear cumulative damage index is computed from the number of prior dives and the ratio between prior maximum pressure and provisional collapse pressure. The relationship is deliberately steep near the collapse estimate. It is not an S-N curve, fracture-mechanics crack-growth model, acoustic-emission interpretation, or composite fatigue model.

Monte Carlo screening interval

The standard analysis varies thickness, diameter, elastic modulus, strength, joint quality, viewport strength, ovality, defect depth, and imperfection amplitude. The 5th, 50th, and 95th percentiles are used to show sensitivity to input uncertainty. Confidence decreases as dispersion increases. This confidence is a numerical input-quality indicator, not a probability that a vehicle is safe.

Why an STL is insufficient. An uploaded STL can support visualization and rough geometric comparison, but it cannot establish a pressure rating unless the structural thickness, materials, layup, joints, penetrations, defects, boundary conditions, and test history are independently defined.

Failure visualization model

The cinematic playback is intentionally connected to the controlling analytical limit state. It is a qualitative educational visualization, not a time-accurate computational fluid-structure interaction solution.

Mode	Playback behavior
Shell buckling	A localized cylindrical band ovalizes and folds inward before the remaining shell rapidly contracts.
Material yield	A broader transition region plastically collapses with distributed inward deformation.
Viewport failure	Failure initiates at the forward transparent pressure boundary and seat region before rapid compartment collapse.
Joint or bond failure	The forward interface separates or slips asymmetrically, followed by rapid inward collapse and fragmentation.
Debris / blackout	Fragments and a pressure-cloud visualization expand while the viewport fades toward blackout. No occupants are depicted.

Interpretation checklist

- Confirm that pressure-hull geometry is not being inferred from cosmetic fairings or an exterior shell.
- Treat first-damage, collapse, proof-test, and operating depths as different concepts.
- Use conservative material properties tied to actual material lots and manufacturing processes.
- Model penetrations, viewports, hatches, rings, welds, bolts, and adhesive interfaces explicitly in professional analysis.
- Use measured imperfections and nondestructive examination rather than assumed quality values.
- Do not use the cinematic sequence as evidence of exact failure timing, debris pattern, or survivability.

Selected references and standards

The application cites these sources as methodological orientation. Access to a title or standard does not imply that the browser implementation complies with it.

American Society of Mechanical Engineers. *PVHO-1-2023: Safety Standard for Pressure Vessels for Human Occupancy.* ASME, New York.

American Society of Mechanical Engineers. *Boiler and Pressure Vessel Code, Section VIII: Rules for Construction of Pressure Vessels.*

National Aeronautics and Space Administration. *Buckling of Thin-Walled Circular Cylinders.* NASA SP-8007, revision 2, 2020.

Timoshenko, Stephen P., and James M. Gere. *Theory of Elastic Stability.* 2nd ed. McGraw-Hill, 1961.

Brush, Don O., and Bo O. Almroth. *Buckling of Bars, Plates, and Shells.* McGraw-Hill, 1975.

Det Norske Veritas. Recommended practices and offshore standards addressing shell buckling and submarine pipeline / shell structures. Applicable edition must be confirmed for professional work.

U.S. Coast Guard Marine Board of Investigation. *Loss of the Titan Submersible.* Results of Investigation released August 5, 2025. The board identified inadequate design, certification, maintenance, and inspection processes among the primary contributing factors.

Marine Technology Society, Submarine Committee. Industry correspondence and guidance concerning independent classification of human-occupied submersibles.

Ross, C. T. F. *Pressure Vessels: External Pressure Technology.* Horwood Publishing, 1990.

Reis, Pedro M. Research literature on imperfection sensitivity and buckling of thin shells, including experimental and numerical studies of localized defects.

Final caution. A design that survives a browser screening model can still fail because of omitted physics, bad assumptions, manufacturing variability, material degradation, inspection error, operational deviation, or governance failure. Human occupancy requires independent, documented, test-backed engineering decisions.