# CDS Models Workflow Manual

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This manual explains which records and model choices supply each calculation in CDS. Follow the workflow from constituents through micromechanics and laminate definition to the applicable load and response. Thermal, moisture and electromagnetic studies have distinct input requirements; a link in the workflow must reflect an actual dependency, not an assumed coupling.

## How to use this manual

Read the assumptions before choosing a model. Keep units consistent, inspect solver notices and use the recorded checks to distinguish a completed calculation from a validated result. Chapter links lead to the interactive website; exercise links open the Workbench. Account-controlled database downloads and classroom materials remain subject to their existing access rules.

Equations are editable Word mathematics. This PDF is exported from the same Word document. Historical reference chapters retain their stated scope; the current workflow and exercise chapters describe the available CDS implementation.

# Contents

# 1 Fully integrated Micro to Macro Engineering

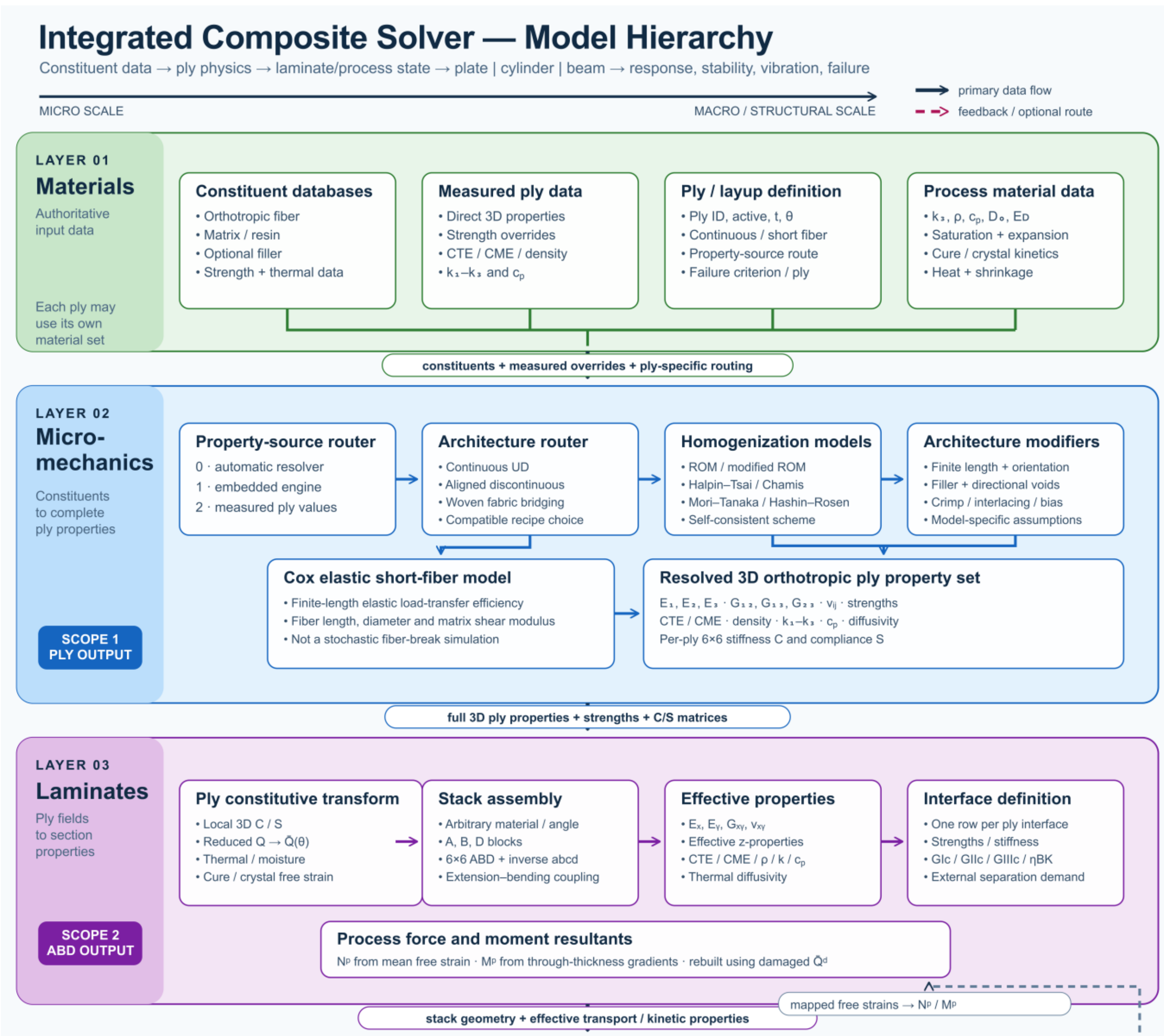
**Online chapter**

Follow one connected engineering record through materials, micromechanics, laminates, processing, structural design, and the CDS cloud.

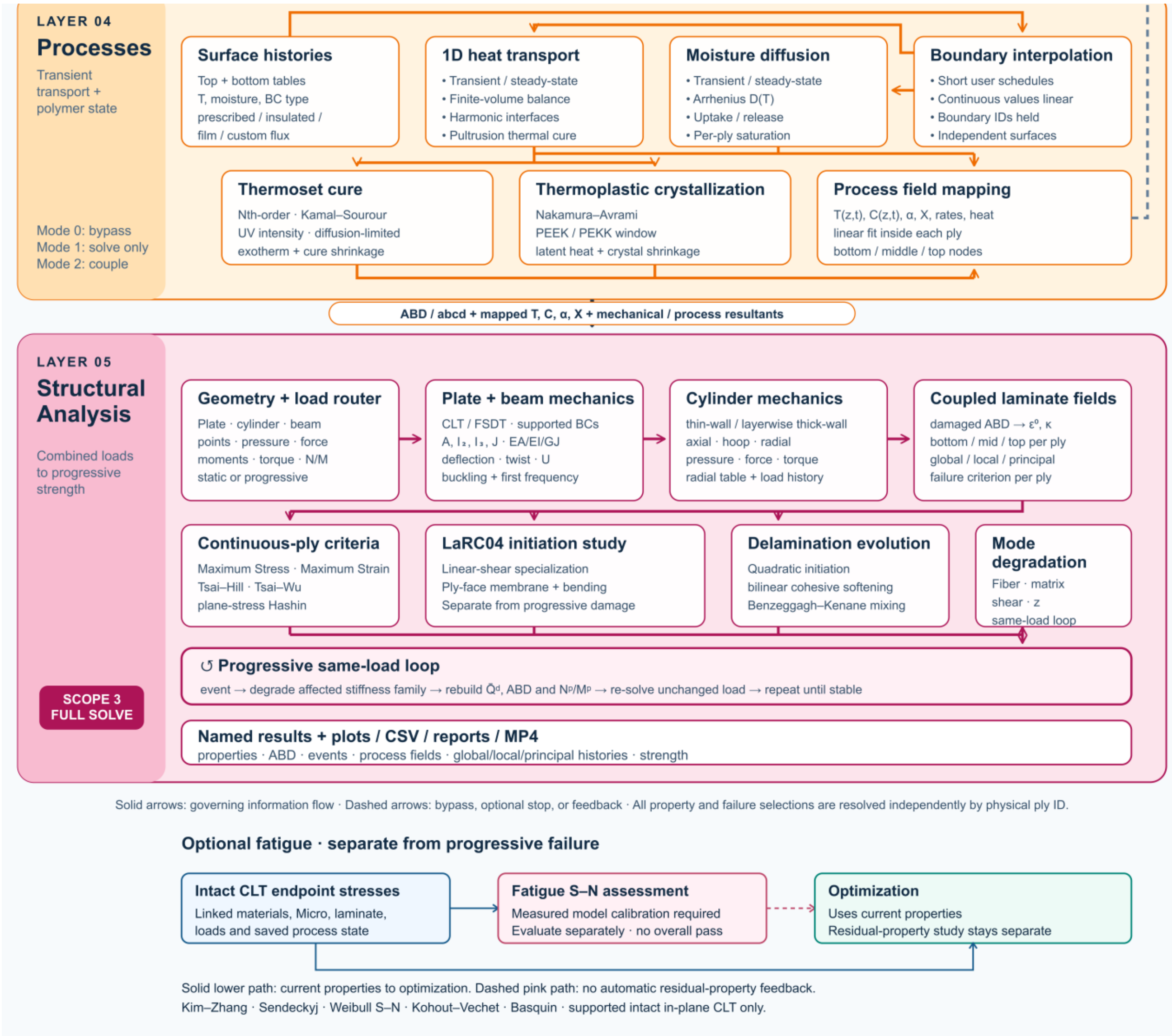
## Integrated solver hierarchy

Select a colored layer to explore its workflow, or a model box to open its theory. The connected study branches below cover all 42 current model families, including the specialist studies.

**Integrated composite solver hierarchy from materials and Cox elastic micromechanics through CLT, FSDT, cylinder mechanics, LaRC04, cohesive delamination and separate fatigue assessment — part 1 of 2**



**Integrated composite solver hierarchy from materials and Cox elastic micromechanics through CLT, FSDT, cylinder mechanics, LaRC04, cohesive delamination and separate fatigue assessment — part 2 of 2**




Each branch has its own compatible inputs and assumptions—not every model runs in one simulation. Fatigue S–N and calibrated residual-property studies are separate from progressive failure; neither automatically changes the saved laminate or optimization properties. ∑ Fatigue theory .

## Connected model branches

### Micromechanics · 9

Input ↓ Constituents, architecture, fractions and calibrated modifiers Result ↓ Reference ply properties for each linked laminate ply

- Halpin–Tsai
- Rule of mixtures
- Modified rule of mixtures
- Chamis
- Mori–Tanaka

- Hashin–Rosen
- Self-consistent scheme
- Woven fabric bridging
- Cox shear-lag elastic

One compatible homogenization model per Micro recipe. Use separate recipes for comparisons; they are not combined in a single ply.

∑ Theory & limits

Exercise

**Cure, crystallization & material transport · 8**

Input ↓ Calibrated kinetics, modulus or transport laws and material assignment Result ↓ Material laws consumed by compatible Micro or transport calculations

- Kamal–Sourour autocatalytic
- Kamal–Sourour with diffusion control
- Nth-order Arrhenius
- CHILE (degree of cure)
- UV intensity-dependent cure
- Nakamura–Avrami
- Temperature-dependent tabular
- 1D Fickian diffusion

Independent model records can be linked together through material inputs. A saved model must be assigned to a material before it contributes to a simulation.

∑ Theory & limits

Exercise

**Thermal transport · 3**

Input ↓ Laminate transport properties, initial state and the thermal case's own surface cycle Result ↓ Temperature and supported polymer-state histories; mapped fields only when coupling is enabled

- 1D transient heat transfer
- 1D steady-state heat transfer
- 1D pultrusion thermal cure

One transport formulation per thermal case. Select its laminate and configure its own initial conditions and surface cycle; pultrusion additionally requires a distance-based die schedule and pulling velocity.

∑ Theory & limits

Exercise

**Moisture transport · 2**

Input ↓ Laminate diffusion properties, initial moisture and its own boundary schedule Result ↓ Moisture history and enabled swelling contribution

- 1D transient moisture diffusion

- 1D steady-state moisture diffusion

One formulation per moisture analysis. Thermal and moisture analyses can both be linked in Simulation; each needs its own boundary conditions.

∑ Theory & limits

Exercise

**Plate · CLT & FSDT · 6**

Input ↓ Laminate stiffness, finite plate dimensions, supported edges and study choice Result ↓ FSDT static bending or selected buckling / modal results; not progressive damage

- CLT
- FSDT
- Static bending
- Modal
- Buckling
- Buckling and modal

Choose a formulation and study. Buckling and modal can be requested together; static bending requires FSDT. These are reference-elastic studies, separate from coupled process or progressive failure.

∑ Theory & limits

Exercise

**Cylinder · 2**

Input ↓ Laminate, cylinder dimensions and formulation-compatible pressure / axial loading Result ↓ Thin-wall membrane response or layerwise radial fields, with distinct assumptions

- Linear thin-wall membrane
- Layerwise thick-wall elasticity

Choose one cylinder formulation per case record. Geometry and plies remain shared; thick-wall radial results exclude torsion and process strains.

∑ Theory & limits

Exercise

**Membrane, bending & beam buckling · 3**

Input ↓ Laminate, compatible section and static or Euler load case Result ↓ Membrane / bending response or separate Euler buckling result

- Linear static
- Linear static with failure indices
- Beam Euler buckling

Geometry and the case determine the membrane or beam-test interpretation. Euler buckling requires a compatible beam section and a separate reference-elastic study; it is not a strength or local-buckling pass.

∑ Theory & limits

Exercise

**Layerwise sections, joints & delamination · 3**

Input ↓ Section or lap geometry, laminate, loads and calibrated interface properties Result ↓ x–z fields; coupled ply damage and delamination only for the supported layerwise plate path

- Layerwise x-z plane strain
- Single-lap x-z plane strain
- Coupled delamination growth

Coupled delamination is available only for the layerwise Plate section and needs calibrated interface and ply properties. Lap-shear uses its separate joint geometry and perfectly bonded elastic formulation.

∑ Theory & limits

Exercise

**Sandwich bending · 1**

Input ↓ Faces, core, dimensions and three-point-bend load Result ↓ Deflection and separate face, core and nominal bond-shear screening

- Sandwich three-point bend

Dedicated sandwich screening. Check core, faces and nominal bond shear separately; peel, mixed-mode debonding and crack growth are not assessed.

∑ Theory & limits

Exercise

**Failure & envelope comparison · 5**

Input ↓ Eligible CLT load case, strengths / strain limits and selected criterion Result ↓ First-ply envelopes or supported progressive ply-damage histories; criteria are not blended

- Maximum stress
- Maximum strain
- Tsai–Hill
- Tsai–Wu
- Hashin

One primary failure criterion per load. In Response → Failure, compare all eligible theories or a custom selection in the envelope controls. Each theory runs independently; criteria are not blended.

∑ Theory & limits

Exercise

**Fatigue S–N · 5**

Input ↓ Intact ply stresses, cyclic loads and measured S–N calibration Result ↓ Separate life assessment; no automatic laminate degradation

- Kim–Zhang
- Sendeckyj

- Weibull S–N
- Kohout–Vechet
- Basquin

Select calibrated S–N curves for each material, direction and stress sign in Fatigue. Different sources can use different models. S–N life does not define residual stiffness or strength.

∑ Theory & limits

Exercise

**D6641 · Compression coupon · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

- Virtual test · compression coupon

Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

∑ Theory & limits

Exercise

**D5379 / D7078 · Shear coupon · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

- Virtual test · nominal shear coupon

Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

∑ Theory & limits

Exercise

**D5528 · DCB opening · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

- Virtual test · DCB beam compliance

Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

∑ Theory & limits

Exercise

**D7905 · ENF sliding · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

- Virtual test · ENF beam compliance

Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

∑ Theory & limits

Exercise

**D6671 · Mixed-mode fracture envelope · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

- Virtual test · BK mixed-mode envelope

Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

∑ Theory & limits

Exercise

**D5229 · Moisture uptake calibration · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

- Virtual test · Fickian uptake calibration

Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

∑ Theory & limits

Exercise

**D5961 · Bearing / bypass screening · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

- Virtual test · bearing bypass screening

Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

∑ Theory & limits

Exercise

**D6484 · Open-hole compression · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

- Virtual test · measured open-hole compression

Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

∑ Theory & limits

Exercise

**D6742 · Filled-hole comparison · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

- Virtual test · measured filled-hole comparison

Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

∑ Theory & limits

Exercise

**D7136 / D7137 · Impact & CAI assessment · 1**

Input ↓ Linked laminate and explicit specimen, load or measured calibration inputs Result ↓ Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

- Virtual test · measured impact and CAI

Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

∑ Theory & limits

Exercise

**Open-hole strength · 1**

Input ↓ Specially orthotropic laminate, hole radius, unnotched strength and calibrated distances Result ↓ Point / average stress strength screening and radial stress profile

- Whitney–Nuismer open-hole tension

Infinite-width, specially orthotropic tension screening. Point and average stress distances must be calibrated independently for this laminate. Not compression, bearing or a joint allowable.

∑ Theory & limits

Exercise

**Creep & stress relaxation · 1**

Input ↓ Laminate Ex, Prony fractions / times and held stress or strain at calibration temperature Result ↓ Separate axial creep and relaxation curves with time-refinement safeguards

- Generalized Maxwell · axial Prony

Linear uniaxial response at the calibration temperature. Reference Ex is the instantaneous modulus. Three Maxwell branches; creep is solved from stress equilibrium, not the reciprocal relaxation modulus. No thermal shifting or nonlinear creep.

∑ Theory & limits

Exercise

**Analytical bonded joint · 1**

Input ↓ Identical equivalent-elastic adherends, adhesive, overlap, width and tensile force Result ↓ Volkersen shear and Goland–Reissner shear / peel; no debond growth

- Volkersen & Goland–Reissner joint

Identical equivalent-elastic adherends, long free arms and a thin elastic adhesive. Compare shear-only Volkersen with eccentric single-lap shear and peel. Not a debonding, plasticity or strength calculation.

∑ Theory & limits

Exercise

**LaRC04 failure initiation · 1**

Input ↓ Laminate, membrane / bending resultants and calibrated effective ply strengths Result ↓ Linear-shear LaRC04 initiation indices at ply faces; no progressive degradation

- LaRC04 · linear shear

NASA LaRC04 linear-shear specialization, evaluated at both faces of every ply under membrane and bending loads. Supplied ply strengths are effective/in-situ values; no automatic thin-ply enhancement. Initiation only, not degradation or nonlinear-shear instability.

∑ Theory & limits

Exercise

**Tool-release shape · 1**

Input ↓ Laminate and prescribed temperatures, CTE and effective post-gel shrinkage Result ↓ Free-release CLT curvature and separate corner spring-in estimate; not an automatic process-history handoff

- Free-release eigenstrain & spring-in

Free CLT release from prescribed ply-local shrinkage/thermal eigenstrains. Corner spring-in is a separate uniform-strain estimate. Stress-free temperature and effective post-gel shrinkage need calibration. No tool friction, cure kinetics or viscoelastic restraint history.

∑ Theory & limits

Exercise

**Fatigue residual properties · 1**

Input ↓ Modulus, independently fitted stiffness / strength retention laws, life and elapsed cycles Result ↓ Residual-property curves for the specified constant-amplitude calibration; saved laminate is unchanged

- Calibrated residual-property fatigue

Prescribed power-law retention fitted to constant-amplitude tests at a fixed stress ratio, amplitude and temperature. Stiffness and strength have independent coefficients. S–N life alone cannot calibrate either. Does not modify the saved laminate.

∑ Theory & limits

Exercise

**Cylinder buckling · 1**

Input ↓ Thin specially orthotropic shell, radius, length, axial compression and prescribed knockdown Result ↓ Ideal / knocked-down Donnell axial buckling and governing mode; no pressure or postbuckling

- Donnell cylinder · axial buckling

Simply supported, thin, specially orthotropic cylinder under uniform axial compression. Discrete Donnell modes; prescribed knockdown factor explores imperfection sensitivity, not a prediction from measured imperfection amplitude. No pressure, torsion, postbuckling or strength pass.

∑ Theory & limits

Exercise

**Uncertainty & sensitivity · 1**

Input ↓ Laminate, bounded modulus / thickness / angle variations, seed and axial load Result ↓ ABD axial-strain percentiles and signed correlations; not certified reliability

- Seeded laminate uncertainty

Seeded independent uniform sampling of shared modulus, ply-thickness and angle offsets. Recomputes laminate ABD for each sample. Bounds are assumptions, not measured distributions. Percentiles and sensitivity are exploratory, not reliability certification.

∑ Theory & limits

Exercise

**Wiener series and parallel · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Wiener series and parallel

Positive lossless dielectric bounds; complex directional estimates.

∑ Theory & limits

Exercise

**Looyenga / Landau–Lifshitz–Looyenga · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Looyenga / Landau–Lifshitz–Looyenga

One cube-root mixing law, not two independent models.

∑ Theory & limits

Exercise

**Maxwell–Garnett · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Maxwell–Garnett

Dilute subwavelength spherical inclusions in a host.

∑ Theory & limits

Exercise

**Normal-incidence laminate TMM · 1**

Input ↓ Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Result ↓ Reflection, transmission, absorption and shielding spectra; no mechanical coupling

- EM · Normal-incidence laminate TMM

Coherent isotropic nonmagnetic layers between air half-spaces.

∑ Theory & limits

Exercise

**Bruggeman symmetric EMT · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Bruggeman symmetric EMT

Two positive-permittivity phases; no explicit contact network.

∑ Theory & limits

Exercise

**EM Mori–Tanaka · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · EM Mori–Tanaka

Scalar principal-axis ellipsoidal field approximation.

∑ Theory & limits

Exercise

**EM self-consistent · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · EM self-consistent

Scalar principal-axis self-consistency; spherical case equals Bruggeman.

∑ Theory & limits

Exercise

**Differential effective medium · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Differential effective medium

Incremental mixing with time-step refinement check.

∑ Theory & limits

Exercise

**Coated sphere and interphase · 1**

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Coated sphere and interphase

Concentric subwavelength coated spheres; no dynamic Mie scattering.

∑ Theory & limits

Exercise

#### Generalized multiphase EMT · 1

Input ↓ Explicit host/inclusion electrical properties and fractions Result ↓ Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

- EM · Generalized multiphase EMT

Spherical multiphase Bruggeman with convergence checks.

∑ Theory & limits

Exercise

#### Oblique polarized laminate TMM · 1

Input ↓ Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Result ↓ Reflection, transmission, absorption and shielding spectra; no mechanical coupling

- EM · Oblique polarized laminate TMM

TE or TM waves; scalar isotropic layers, no polarization conversion.

∑ Theory & limits

Exercise

#### 1D transmission line matrix · 1

Input ↓ Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Result ↓ Reflected and transmitted pulse histories and spectra; mesh and energy checks

- EM · 1D transmission line matrix

Normal-incidence lossless delay-line mesh with pulse decay, energy and mesh-refinement safeguards. Explicit Run required; not a 3D solver.

∑ Theory & limits

Exercise

#### 1D Floquet–Bloch periodic layers · 1

Input ↓ Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Result ↓ Periodic-cell eigenvalues, folded Bloch phase and stop-band decay

- EM · 1D Floquet–Bloch periodic layers

Lossless isotropic A/B unit-cell eigenvalues, folded Bloch phase and stop-band attenuation at normal incidence. Not arbitrary-cell homogenization.

∑ Theory & limits

Exercise

## Select cases and inspect your model

### Inspect the selected model in Live Sim

SIMULATE opens with Live Sim, an input-driven view of the selected cases. The four selectors remain available above the scene. Switch to Blocks to manage candidate records and trace their connections.

- Select Geometry, Laminate, a constituent or a case to inspect the inputs that are actually used. Clicking a used block heading also opens its Live Sim inspection.
- Select a ply in the stack or geometry view to inspect its source. Micro-derived and stored-property plies are identified separately. Woven sources show the fabric unit-cell preview when applicable.
- Select the Thermal or Moisture case to inspect its surface boundary schedule. Move the step slider to compare prescribed conditions. This is not a solved internal temperature or moisture field.
- Use Edit input to open the source record. The scene follows the changed inputs; rerun the simulation before trusting previous results.

Geometry, ply bands and arrows are input illustrations, not a finite-element mesh or solved deformation. Display-only thickness enlargement and any model-specific visualization assumptions are identified in the preview.

### Choose the run in the SIMULATION block

SIMULATION is the control point for the run. Select a Thermal case, Moisture case, Mechanical case and EM case, or None in any slot. Each selected case shows its analysis model, laminate and applicable geometry.

- Keep candidate records in the surrounding blocks. Adding a candidate does not select it for execution.
- Select the required cases in SIMULATION and review their inputs before Run. At least one case is required.
- Use the same laminate for a supported combined run. Run standalone studies separately with the other selectors set to None.
- Run executes the selected combination. A connection or Used marker is not evidence of a successful solve.

Selecting several cases does not add unsupported physics coupling. EM screening studies do not automatically heat the thermal case.

### Review every downstream geometry dependency

A geometry record can be shared by several cases and simulations. Editing its dimensions or type affects all linked consumers, including studies that are not currently open. Unrelated records are unchanged.

- After editing geometry, open Solver messages and expand Review affected cases and simulations. Select a linked name to inspect that record.
- Check the selected model, load basis, dimensions and boundary conditions. Loads are not automatically replaced when the geometry changes.
- Resolve incompatible geometry and model combinations before running. An I-section does not turn a plate theory into a beam theory.
- Rerun affected simulations before relying on previous results. Inputs changed warnings indicate that stored results no longer match their connected inputs.

Geometry affects only dimensions consumed by the selected model. One-dimensional transport retains its through-thickness assumptions; standalone studies may own their dimensions. Under fixed total edge loads, changing plate width changes force per unit width. Under prescribed resultants, it does not.

Complete block workflow guide

## RF and microwave studies

Dielectric phase inputs → Effective medium → manual property handoff → RF laminate and EM field → Reflection · transmission · shielding

Separate RF screening studies use measured electrical properties. They do not infer dielectric behavior from mechanical data or automatically couple electromagnetic heating into a process cycle.

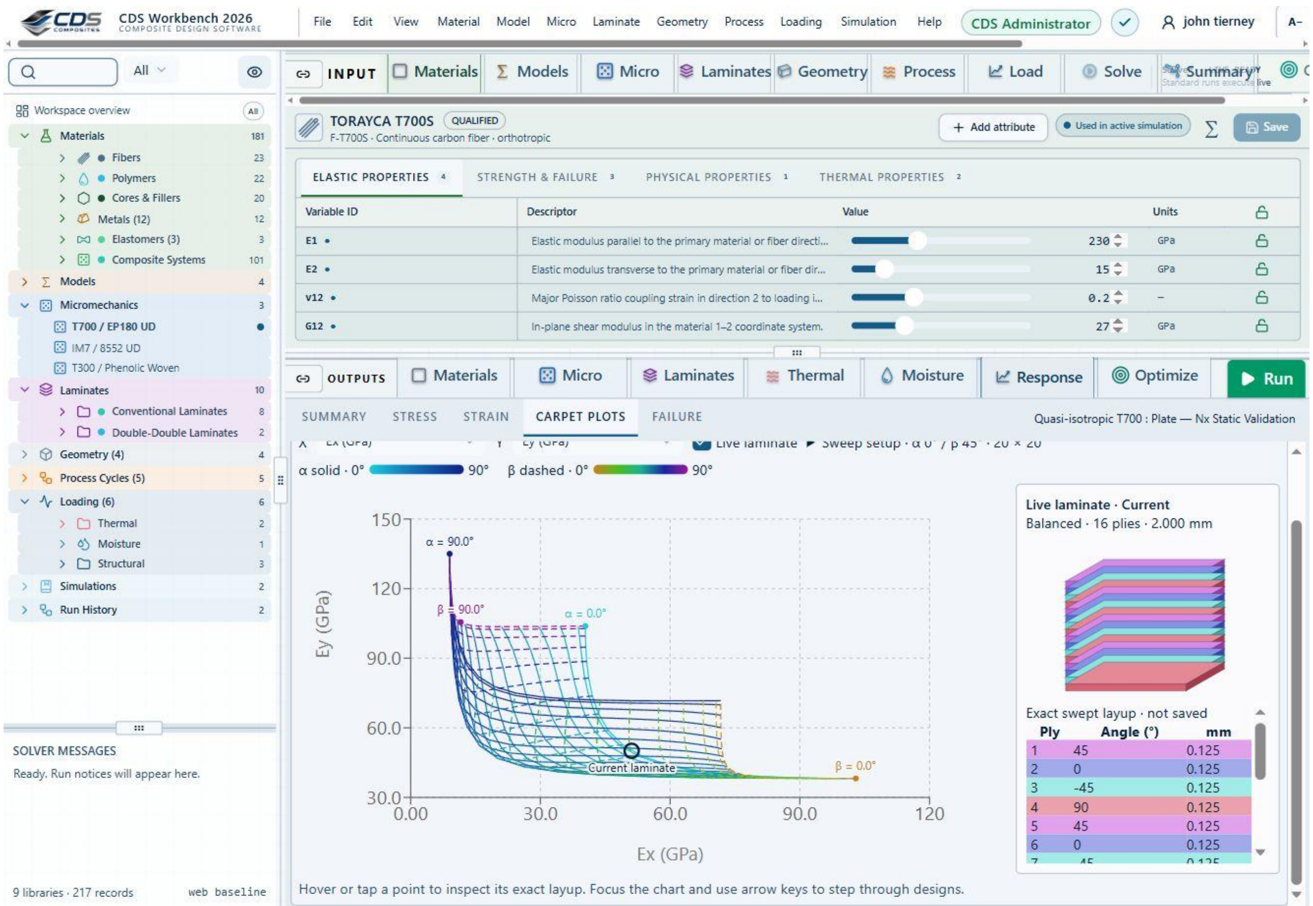
Models, equations, worked example and limits

# 2 Turn model output into repeatable engineering evidence

**Online chapter**

CDS solves the handoff from analysis to decision by linking comparisons, fields, tables, parametric studies, and open exports across the complete composite model chain.

### 02.7 / Workbench — Engineering evidence & automation Open full-size view




A linked carpet plot and laminate stack make the selected design visible alongside its properties.

Workbench capture · September 6, 2026 . Representative interface and demo data, not a new solver run or validation certificate. Control locations may differ in later releases.

Trace the selected input path

Ply property source

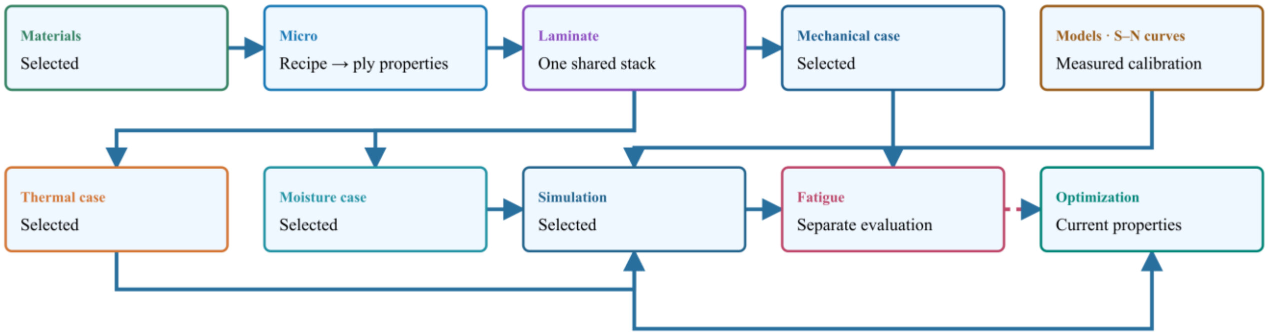
Include thermal analysis

Include moisture analysis

Include optional fatigue assessment

Stored ply properties bypass Micro. Mixed stacks keep both paths. Gray blocks are not selected. Geometry, process schedules and other model records are omitted here for clarity; a real run must include all required references.

Fatigue uses intact CLT endpoint stresses and measured S–N calibration. It is evaluated separately from Run and progressive failure. The dashed handoff is not active: optimization still uses current properties until a degradation law is supplied.




Dashed pink arrow: residual-fatigue study is separate—not an automatic property transfer.

Materials → Micro → Laminate.

02.7 / How CDS solves it

From engineering question to evidence

## Compare properties

Select one or more materials, laminas, laminates, simulations or optimization snapshots and review scrollable tables, bar charts, Ashby plots, line plots, property maps, and laminate stiffness matrices.

## Explore field response

Move result cursors through time and thickness to update linked thermal plots, or select stress, strain, displacement, resultant, and factor-of-safety views for a structural case.

## Export the evidence

Right-click supported tables to save CSV or XLSX data and presentation-oriented PPTX output where available, or write supported material cards for downstream finite-element analysis.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

**Released models, connections and theory**

Complete model directory

### ∑ Micromechanics

Models browser → Micromechanics · source: Micro

Inputs Constituents, architecture, fractions and calibrated modifiers Results / handoff Reference ply properties for each linked laminate ply

One compatible homogenization model per Micro recipe. Use separate recipes for comparisons; they are not combined in a single ply.

**Formulations and study choices**

- Halpin–Tsai
- Rule of mixtures
- Modified rule of mixtures
- Chamis
- Mori–Tanaka
- Hashin–Rosen
- Self-consistent scheme
- Woven fabric bridging
- Cox shear-lag elastic

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cure, crystallization & material transport

Models → material-model folders · assigned through Materials

Inputs Calibrated kinetics, modulus or transport laws and material assignment Results / handoff Material laws consumed by compatible Micro or transport calculations

Independent model records can be linked together through material inputs. A saved model must be assigned to a material before it contributes to a simulation.

**Formulations and study choices**

- Kamal–Sourour autocatalytic
- Kamal–Sourour with diffusion control
- Nth-order Arrhenius
- CHILE (degree of cure)
- UV intensity-dependent cure
- Nakamura–Avrami
- Temperature-dependent tabular
- 1D Fickian diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cure kinetics

· Crystallization kinetics

## ∑ Thermal transport

Models browser → Thermal transport · source: CASES / Thermal

Inputs Laminate transport properties, initial state and the thermal case’s own surface cycle Results / handoff Temperature and supported polymer-state histories; mapped fields only when coupling is enabled

One transport formulation per thermal case. Select its laminate and configure its own initial conditions and surface cycle; pultrusion additionally requires a distance-based die schedule and pulling velocity.

**Formulations and study choices**

- 1D transient heat transfer
- 1D steady-state heat transfer
- 1D pultrusion thermal cure

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Pultrusion exercise

· UV cure exercise

## ∑ Moisture transport

Models browser → Moisture transport · source: CASES / Moisture

Inputs Laminate diffusion properties, initial moisture and its own boundary schedule Results / handoff Moisture history and enabled swelling contribution

One formulation per moisture analysis. Thermal and moisture analyses can both be linked in Simulation; each needs its own boundary conditions.

**Formulations and study choices**

- 1D transient moisture diffusion
- 1D steady-state moisture diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Plate · CLT & FSDT

Structural models → Laminate mechanics · CLT / FSDT

Inputs Laminate stiffness, finite plate dimensions, supported edges and study choice Results / handoff FSDT static bending or selected buckling / modal results; not progressive damage

Choose a formulation and study. Buckling and modal can be requested together; static bending requires FSDT. These are reference-elastic studies, separate from coupled process or progressive failure.

**Formulations and study choices**

- CLT
- FSDT
- Static bending
- Modal
- Buckling
- Buckling and modal

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cylinder

Structural models → Cylinder models

Inputs Laminate, cylinder dimensions and formulation-compatible pressure / axial loading Results / handoff Thin-wall membrane response or layerwise radial fields, with distinct assumptions

Choose one cylinder formulation per case record. Geometry and plies remain shared; thick-wall radial results exclude torsion and process strains.

**Formulations and study choices**

- Linear thin-wall membrane
- Layerwise thick-wall elasticity

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Layerwise thick-wall theory

## ∑ Membrane, bending & beam buckling

Structural models → Laminate mechanics → Membrane, bending & beam

Inputs Laminate, compatible section and static or Euler load case Results / handoff Membrane / bending response or separate Euler buckling result

Geometry and the case determine the membrane or beam-test interpretation. Euler buckling requires a compatible beam section and a separate reference-elastic study; it is not a strength or local-buckling pass.

**Formulations and study choices**

- Linear static
- Linear static with failure indices
- Beam Euler buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Layerwise sections, joints & delamination

Structural models → Layerwise sections & joints

Inputs Section or lap geometry, laminate, loads and calibrated interface properties Results / handoff x–z fields; coupled ply damage and delamination only for the supported layerwise plate path

Coupled delamination is available only for the layerwise Plate section and needs calibrated interface and ply properties. Lap-shear uses its separate joint geometry and perfectly bonded elastic formulation.

**Formulations and study choices**

- Layerwise x-z plane strain
- Single-lap x-z plane strain
- Coupled delamination growth

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cohesive interface theory

### ∑ Sandwich bending

Structural models → Sandwich bending

Inputs Faces, core, dimensions and three-point-bend load Results / handoff Deflection and separate face, core and nominal bond-shear screening

Dedicated sandwich screening. Check core, faces and nominal bond shear separately; peel, mixed-mode debonding and crack growth are not assessed.

**Formulations and study choices**

- Sandwich three-point bend

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Failure & envelope comparison

Structural models → Laminate mechanics → Failure criteria

Inputs Eligible CLT load case, strengths / strain limits and selected criterion Results / handoff First-ply envelopes or supported progressive ply-damage histories; criteria are not blended

One primary failure criterion per load. In Response → Failure, compare all eligible theories or a custom selection in the envelope controls. Each theory runs independently; criteria are not blended.

**Formulations and study choices**

- Maximum stress
- Maximum strain
- Tsai–Hill
- Tsai–Wu
- Hashin

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Failure equations

· Implemented Workbench methods

### ∑ Fatigue S–N

Structural models → Laminate mechanics → Fatigue

Inputs Intact ply stresses, cyclic loads and measured S–N calibration Results / handoff Separate life assessment; no automatic laminate degradation

Select calibrated S–N curves for each material, direction and stress sign in Fatigue. Different sources can use different models. S–N life does not define residual stiffness or strength.

**Formulations and study choices**

- Kim–Zhang
- Sendeckyj
- Weibull S–N
- Kohout–Vechet
- Basquin

∑ Theory & assumptions

Starter load case · add calibrated fatigue

### ∑ D6641 · Compression coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

**Formulations and study choices**

- Virtual test · compression coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5379 / D7078 · Shear coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

**Formulations and study choices**

- Virtual test · nominal shear coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5528 · DCB opening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

**Formulations and study choices**

- Virtual test · DCB beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7905 · ENF sliding

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

**Formulations and study choices**

- Virtual test · ENF beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6671 · Mixed-mode fracture envelope

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

**Formulations and study choices**

- Virtual test · BK mixed-mode envelope

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5229 · Moisture uptake calibration

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

**Formulations and study choices**

- Virtual test · Fickian uptake calibration

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5961 · Bearing / bypass screening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

**Formulations and study choices**

- Virtual test · bearing bypass screening

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6484 · Open-hole compression

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

**Formulations and study choices**

- Virtual test · measured open-hole compression

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6742 · Filled-hole comparison

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

**Formulations and study choices**

- Virtual test · measured filled-hole comparison

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7136 / D7137 · Impact & CAI assessment

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

**Formulations and study choices**

- Virtual test · measured impact and CAI

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Open-hole strength

Structural models → Laminate mechanics → Failure criteria → Open-hole strength

Inputs Specially orthotropic laminate, hole radius, unnotched strength and calibrated distances Results / handoff Point / average stress strength screening and radial stress profile

Infinite-width, specially orthotropic tension screening. Point and average stress distances must be calibrated independently for this laminate. Not compression, bearing or a joint allowable.

**Formulations and study choices**

- Whitney–Nuismer open-hole tension

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Creep & stress relaxation

Structural models → Laminate mechanics → Creep & stress relaxation

Inputs Laminate Ex, Prony fractions / times and held stress or strain at calibration temperature Results / handoff Separate axial creep and relaxation curves with time-refinement safeguards

Linear uniaxial response at the calibration temperature. Reference Ex is the instantaneous modulus. Three Maxwell branches; creep is solved from stress equilibrium, not the reciprocal relaxation modulus. No thermal shifting or nonlinear creep.

**Formulations and study choices**

- Generalized Maxwell · axial Prony

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Analytical bonded joint

Structural models → Layerwise sections & joints → Analytical bonded joint

Inputs Identical equivalent-elastic adherends, adhesive, overlap, width and tensile force Results / handoff Volkersen shear and Goland–Reissner shear / peel; no debond growth

Identical equivalent-elastic adherends, long free arms and a thin elastic adhesive. Compare shear-only Volkersen with eccentric single-lap shear and peel. Not a debonding, plasticity or strength calculation.

**Formulations and study choices**

- Volkersen & Goland–Reissner joint

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ LaRC04 failure initiation

Structural models → Laminate mechanics → Failure criteria → LaRC04

Inputs Laminate, membrane / bending resultants and calibrated effective ply strengths Results / handoff Linear-shear LaRC04 initiation indices at ply faces; no progressive degradation

NASA LaRC04 linear-shear specialization, evaluated at both faces of every ply under membrane and bending loads. Supplied ply strengths are effective/in-situ values; no automatic thin-ply enhancement. Initiation only, not degradation or nonlinear-shear instability.

**Formulations and study choices**

- LaRC04 · linear shear

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Tool-release shape

Structural models → Tool-release shape

Inputs Laminate and prescribed temperatures, CTE and effective post-gel shrinkage Results / handoff Free-release CLT curvature and separate corner spring-in estimate; not an automatic process-history handoff

Free CLT release from prescribed ply-local shrinkage/thermal eigenstrains. Corner spring-in is a separate uniform-strain estimate. Stress-free temperature and effective post-gel shrinkage need calibration. No tool friction, cure kinetics or viscoelastic restraint history.

**Formulations and study choices**

- Free-release eigenstrain & spring-in

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Fatigue residual properties

Structural models → Laminate mechanics → Fatigue → Residual properties

Inputs Modulus, independently fitted stiffness / strength retention laws, life and elapsed cycles Results / handoff Residual-property curves for the specified constant-amplitude calibration; saved laminate is unchanged

Prescribed power-law retention fitted to constant-amplitude tests at a fixed stress ratio, amplitude and temperature. Stiffness and strength have independent coefficients. S–N life alone cannot calibrate either. Does not modify the saved laminate.

**Formulations and study choices**

- Calibrated residual-property fatigue

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cylinder buckling

Structural models → Cylinder models → Cylinder buckling

Inputs Thin specially orthotropic shell, radius, length, axial compression and prescribed knockdown Results / handoff Ideal / knocked-down Donnell axial buckling and governing mode; no pressure or postbuckling

Simply supported, thin, specially orthotropic cylinder under uniform axial compression. Discrete Donnell modes; prescribed knockdown factor explores imperfection sensitivity, not a prediction from measured imperfection amplitude. No pressure, torsion, postbuckling or strength pass.

**Formulations and study choices**

- Donnell cylinder · axial buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Uncertainty & sensitivity

Structural models → Uncertainty & sensitivity

Inputs Laminate, bounded modulus / thickness / angle variations, seed and axial load Results / handoff ABD axial-strain percentiles and signed correlations; not certified reliability

Seeded independent uniform sampling of shared modulus, ply-thickness and angle offsets. Recomputes laminate ABD for each sample. Bounds are assumptions, not measured distributions. Percentiles and sensitivity are exploratory, not reliability certification.

**Formulations and study choices**

- Seeded laminate uncertainty

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Wiener series and parallel

Models → Electromagnetics · RF → Wiener series and parallel

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Positive lossless dielectric bounds; complex directional estimates.

**Formulations and study choices**

- EM · Wiener series and parallel

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Looyenga / Landau–Lifshitz–Looyenga

Models → Electromagnetics · RF → Looyenga / Landau–Lifshitz–Looyenga

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

One cube-root mixing law, not two independent models.

**Formulations and study choices**

- EM · Looyenga / Landau–Lifshitz–Looyenga

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Maxwell–Garnett

Models → Electromagnetics · RF → Maxwell–Garnett

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Dilute subwavelength spherical inclusions in a host.

**Formulations and study choices**

- EM · Maxwell–Garnett

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Normal-incidence laminate TMM

Models → Electromagnetics · RF → Normal-incidence laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

Coherent isotropic nonmagnetic layers between air half-spaces.

**Formulations and study choices**

- EM · Normal-incidence laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Bruggeman symmetric EMT

Models → Electromagnetics · RF → Bruggeman symmetric EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Two positive-permittivity phases; no explicit contact network.

**Formulations and study choices**

- EM · Bruggeman symmetric EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM Mori–Tanaka

Models → Electromagnetics · RF → EM Mori–Tanaka

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis ellipsoidal field approximation.

**Formulations and study choices**

- EM · EM Mori–Tanaka

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM self-consistent

Models → Electromagnetics · RF → EM self-consistent

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis self-consistency; spherical case equals Bruggeman.

**Formulations and study choices**

- EM · EM self-consistent

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Differential effective medium

Models → Electromagnetics · RF → Differential effective medium

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Incremental mixing with time-step refinement check.

**Formulations and study choices**

- EM · Differential effective medium

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Coated sphere and interphase

Models → Electromagnetics · RF → Coated sphere and interphase

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Concentric subwavelength coated spheres; no dynamic Mie scattering.

**Formulations and study choices**

- EM · Coated sphere and interphase

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Generalized multiphase EMT

Models → Electromagnetics · RF → Generalized multiphase EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Spherical multiphase Bruggeman with convergence checks.

**Formulations and study choices**

- EM · Generalized multiphase EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Oblique polarized laminate TMM

Models → Electromagnetics · RF → Oblique polarized laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

TE or TM waves; scalar isotropic layers, no polarization conversion.

**Formulations and study choices**

- EM · Oblique polarized laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D transmission line matrix

Models → Electromagnetics · RF → 1D transmission line matrix

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflected and transmitted pulse histories and spectra; mesh and energy checks

Normal-incidence lossless delay-line mesh with pulse decay, energy and mesh-refinement safeguards. Explicit Run required; not a 3D solver.

**Formulations and study choices**

- EM · 1D transmission line matrix

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D Floquet–Bloch periodic layers

Models → Electromagnetics · RF → 1D Floquet–Bloch periodic layers

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Periodic-cell eigenvalues, folded Bloch phase and stop-band decay

Lossless isotropic A/B unit-cell eigenvalues, folded Bloch phase and stop-band attenuation at normal incidence. Not arbitrary-cell homogenization.

**Formulations and study choices**

- EM · 1D Floquet–Bloch periodic layers

∑ Theory & assumptions

Guided exercise & two-layer workflow

Outcomes and boundaries

- Results update from the active tree selection
- Charts and tables provide complementary views of the same solution
- Mechanical, thermal, moisture, and total response can be reviewed separately

Delivered capability

Methods available in CDS

Bar charts compare up to three properties; Ashby views compare any two

Linear and logarithmic scales are available for property comparison

Legend hover highlights its plotted records when practical

3D views provide fill, opacity, extrema and autoscale controls

Thermal cursors link time-history and through-thickness plots

Right-click supported tables to export CSV, XLSX or PPTX evidence

Next capability 02.1 Connected engineering data →

# 3 Connect engineering work through the CDS cloud

**Online chapter**

Extend the integrated model chain into secure collaboration, managed user access, versioned engineering records, shared examples, license delivery, and reusable cloud-supported workflows.

03.6 / Workflow focus

Connected engineering record

## Connected user accounts

One verified CDS account connects licensing, approved downloads, forum participation, and shared engineering resources without requiring a ChatGPT login.

## Versioned engineering records

Model inputs, assumptions, releases, and outputs can be organized as traceable records so a design decision can be revisited and reproduced.

## Shared examples and guidance

Source-grounded examples, technical references, workflow guidance, and training remain available alongside the models they explain.

## Account entitlement

The cloud account workflow authorizes project roles, module access, Recipe execution, and result retrieval through the same secured user record.

## Collaboration and forum

Engineers can discuss methods, exchange model context, and connect questions to the relevant CDS workflow and theory pages.

## Share an understandable study

Carry material sources, assumptions and results into reports and further analysis so another researcher can follow the engineering reasoning.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

Next workflow page 03.1 Materials →

# 4 Evaluate the complete composite structure

**Online chapter**

Choose a compatible released plate, cylinder, beam, section, joint or analytical study. Shared laminate inputs do not make every model combination valid.

## Select cases and inspect your model

### Inspect the selected model in Live Sim

SIMULATE opens with Live Sim, an input-driven view of the selected cases. The four selectors remain available above the scene. Switch to Blocks to manage candidate records and trace their connections.

- Select Geometry, Laminate, a constituent or a case to inspect the inputs that are actually used. Clicking a used block heading also opens its Live Sim inspection.
- Select a ply in the stack or geometry view to inspect its source. Micro-derived and stored-property plies are identified separately. Woven sources show the fabric unit-cell preview when applicable.
- Select the Thermal or Moisture case to inspect its surface boundary schedule. Move the step slider to compare prescribed conditions. This is not a solved internal temperature or moisture field.
- Use Edit input to open the source record. The scene follows the changed inputs; rerun the simulation before trusting previous results.

Geometry, ply bands and arrows are input illustrations, not a finite-element mesh or solved deformation. Display-only thickness enlargement and any model-specific visualization assumptions are identified in the preview.

### Choose the run in the SIMULATION block

SIMULATION is the control point for the run. Select a Thermal case, Moisture case, Mechanical case and EM case, or None in any slot. Each selected case shows its analysis model, laminate and applicable geometry.

- Keep candidate records in the surrounding blocks. Adding a candidate does not select it for execution.
- Select the required cases in SIMULATION and review their inputs before Run. At least one case is required.
- Use the same laminate for a supported combined run. Run standalone studies separately with the other selectors set to None.
- Run executes the selected combination. A connection or Used marker is not evidence of a successful solve.

Selecting several cases does not add unsupported physics coupling. EM screening studies do not automatically heat the thermal case.

### Review every downstream geometry dependency

A geometry record can be shared by several cases and simulations. Editing its dimensions or type affects all linked consumers, including studies that are not currently open. Unrelated records are unchanged.

- After editing geometry, open Solver messages and expand Review affected cases and simulations. Select a linked name to inspect that record.

- Check the selected model, load basis, dimensions and boundary conditions. Loads are not automatically replaced when the geometry changes.
- Resolve incompatible geometry and model combinations before running. An I-section does not turn a plate theory into a beam theory.
- Rerun affected simulations before relying on previous results. Inputs changed warnings indicate that stored results no longer match their connected inputs.

Geometry affects only dimensions consumed by the selected model. One-dimensional transport retains its through-thickness assumptions; standalone studies may own their dimensions. Under fixed total edge loads, changing plate width changes force per unit width. Under prescribed resultants, it does not.

Complete block workflow guide

Trace the selected input path

Ply property source

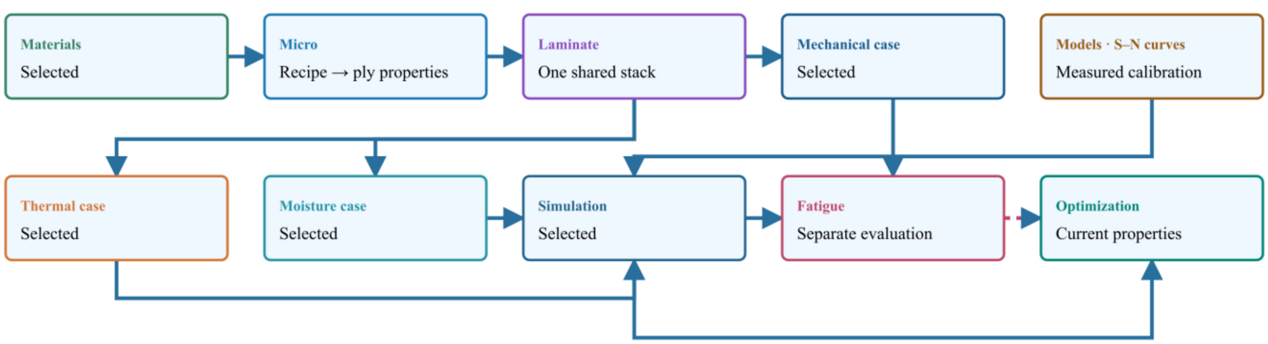
Include thermal analysis

Include moisture analysis

Include optional fatigue assessment

Stored ply properties bypass Micro. Mixed stacks keep both paths. Gray blocks are not selected. Geometry, process schedules and other model records are omitted here for clarity; a real run must include all required references.

Fatigue uses intact CLT endpoint stresses and measured S–N calibration. It is evaluated separately from Run and progressive failure. The dashed handoff is not active: optimization still uses current properties until a degradation law is supplied.




Dashed pink arrow: residual-fatigue study is separate—not an automatic property transfer.

Materials → Micro → Laminate.

03.5 / Workflow focus

Connected engineering record

## Plate and beam response

Use the released CLT/FSDT finite-plate or membrane/beam path with compatible dimensions, loads and supports. Buckling, modal and static bending are distinct study choices.

## Cylinder formulations

Thin-wall membrane and layerwise thick-wall elasticity have different load and process limits. Donnell axial buckling is a separate thin-shell study with an explicit knockdown factor.

## Sections and joints

Layerwise sections, lap joints and sandwich bending have their own geometry and interfaces. The analytical Volkersen / Goland–Reissner study is a separate identical-adherend elastic approximation.

## Failure and notches

The five existing criteria support eligible CLT first-ply / progressive calculations. LaRC04 linear-shear initiation and calibrated open-hole strength are separate studies, not additional progressive choices.

## Fatigue

S–N models predict life from calibrated data. Residual stiffness / strength requires independently fitted retention laws in its separate study; neither automatically changes optimization properties.

## Creep shape and uncertainty

Reference-state studies explore time response, prescribed-eigenstrain free release and bounded ABD sampling. Their scope, inputs and output handoffs are listed below.

## Keep evidence connected

Run the selected Simulation after relevant edits. Review model assumptions, stale-result warnings, convergence and calibration before interpreting the result.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

## Design released model connections

Expand a family for inputs, outputs, supported formulations, theory and an exercise. All model families

### ∑ Plate · CLT & FSDT

Structural models → Laminate mechanics · CLT / FSDT

Inputs Laminate stiffness, finite plate dimensions, supported edges and study choice Results / handoff FSDT static bending or selected buckling / modal results; not progressive damage

Choose a formulation and study. Buckling and modal can be requested together; static bending requires FSDT. These are reference-elastic studies, separate from coupled process or progressive failure.

**Formulations and study choices**

- CLT
- FSDT
- Static bending

- Modal
- Buckling
- Buckling and modal

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cylinder

Structural models → Cylinder models

Inputs Laminate, cylinder dimensions and formulation-compatible pressure / axial loading Results / handoff Thin-wall membrane response or layerwise radial fields, with distinct assumptions

Choose one cylinder formulation per case record. Geometry and plies remain shared; thick-wall radial results exclude torsion and process strains.

### Formulations and study choices

- Linear thin-wall membrane
- Layerwise thick-wall elasticity

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Layerwise thick-wall theory

## ∑ Membrane, bending & beam buckling

Structural models → Laminate mechanics → Membrane, bending & beam

Inputs Laminate, compatible section and static or Euler load case Results / handoff Membrane / bending response or separate Euler buckling result

Geometry and the case determine the membrane or beam-test interpretation. Euler buckling requires a compatible beam section and a separate reference-elastic study; it is not a strength or local-buckling pass.

### Formulations and study choices

- Linear static
- Linear static with failure indices
- Beam Euler buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Layerwise sections, joints & delamination

Structural models → Layerwise sections & joints

Inputs Section or lap geometry, laminate, loads and calibrated interface properties Results / handoff x–z fields; coupled ply damage and delamination only for the supported layerwise plate path

Coupled delamination is available only for the layerwise Plate section and needs calibrated interface and ply properties. Lap-shear uses its separate joint geometry and perfectly bonded elastic formulation.

**Formulations and study choices**

- Layerwise x-z plane strain
- Single-lap x-z plane strain
- Coupled delamination growth

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cohesive interface theory

**∑ Sandwich bending**

Structural models → Sandwich bending

Inputs Faces, core, dimensions and three-point-bend load Results / handoff Deflection and separate face, core and nominal bond-shear screening

Dedicated sandwich screening. Check core, faces and nominal bond shear separately; peel, mixed-mode debonding and crack growth are not assessed.

**Formulations and study choices**

- Sandwich three-point bend

∑ Theory & assumptions

Guided exercise & two-layer workflow

**∑ Failure & envelope comparison**

Structural models → Laminate mechanics → Failure criteria

Inputs Eligible CLT load case, strengths / strain limits and selected criterion Results / handoff First-ply envelopes or supported progressive ply-damage histories; criteria are not blended

One primary failure criterion per load. In Response → Failure, compare all eligible theories or a custom selection in the envelope controls. Each theory runs independently; criteria are not blended.

**Formulations and study choices**

- Maximum stress
- Maximum strain
- Tsai–Hill
- Tsai–Wu
- Hashin

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Failure equations

· Implemented Workbench methods

### ∑ Fatigue S–N

Structural models → Laminate mechanics → Fatigue

Inputs Intact ply stresses, cyclic loads and measured S–N calibration Results / handoff Separate life assessment; no automatic laminate degradation

Select calibrated S–N curves for each material, direction and stress sign in Fatigue. Different sources can use different models. S–N life does not define residual stiffness or strength.

**Formulations and study choices**

- Kim–Zhang
- Sendeckyj
- Weibull S–N
- Kohout–Vechet
- Basquin

∑ Theory & assumptions

Starter load case · add calibrated fatigue

### ∑ D6641 · Compression coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

**Formulations and study choices**

- Virtual test · compression coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5379 / D7078 · Shear coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

**Formulations and study choices**

- Virtual test · nominal shear coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5528 · DCB opening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

**Formulations and study choices**

- Virtual test · DCB beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7905 · ENF sliding

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

**Formulations and study choices**

- Virtual test · ENF beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6671 · Mixed-mode fracture envelope

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

**Formulations and study choices**

- Virtual test · BK mixed-mode envelope

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5229 · Moisture uptake calibration

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

**Formulations and study choices**

- Virtual test · Fickian uptake calibration

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5961 · Bearing / bypass screening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

**Formulations and study choices**

- Virtual test · bearing bypass screening

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6484 · Open-hole compression

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

**Formulations and study choices**

- Virtual test · measured open-hole compression

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6742 · Filled-hole comparison

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

**Formulations and study choices**

- Virtual test · measured filled-hole comparison

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7136 / D7137 · Impact & CAI assessment

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

**Formulations and study choices**

- Virtual test · measured impact and CAI

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Open-hole strength

Structural models → Laminate mechanics → Failure criteria → Open-hole strength

Inputs Specially orthotropic laminate, hole radius, unnotched strength and calibrated distances Results / handoff Point / average stress strength screening and radial stress profile

Infinite-width, specially orthotropic tension screening. Point and average stress distances must be calibrated independently for this laminate. Not compression, bearing or a joint allowable.

**Formulations and study choices**

- Whitney–Nuismer open-hole tension

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Creep & stress relaxation

Structural models → Laminate mechanics → Creep & stress relaxation

Inputs Laminate Ex, Prony fractions / times and held stress or strain at calibration temperature Results / handoff Separate axial creep and relaxation curves with time-refinement safeguards

Linear uniaxial response at the calibration temperature. Reference Ex is the instantaneous modulus. Three Maxwell branches; creep is solved from stress equilibrium, not the reciprocal relaxation modulus. No thermal shifting or nonlinear creep.

**Formulations and study choices**

- Generalized Maxwell · axial Prony

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Analytical bonded joint

Structural models → Layerwise sections & joints → Analytical bonded joint

Inputs Identical equivalent-elastic adherends, adhesive, overlap, width and tensile force Results / handoff Volkersen shear and Goland–Reissner shear / peel; no debond growth

Identical equivalent-elastic adherends, long free arms and a thin elastic adhesive. Compare shear-only Volkersen with eccentric single-lap shear and peel. Not a debonding, plasticity or strength calculation.

**Formulations and study choices**

- Volkersen & Goland–Reissner joint

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ LaRC04 failure initiation

Structural models → Laminate mechanics → Failure criteria → LaRC04

Inputs Laminate, membrane / bending resultants and calibrated effective ply strengths Results / handoff Linear-shear LaRC04 initiation indices at ply faces; no progressive degradation

NASA LaRC04 linear-shear specialization, evaluated at both faces of every ply under membrane and bending loads. Supplied ply strengths are effective/in-situ values; no automatic thin-ply enhancement. Initiation only, not degradation or nonlinear-shear instability.

**Formulations and study choices**

- LaRC04 · linear shear

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Tool-release shape

Structural models → Tool-release shape

Inputs Laminate and prescribed temperatures, CTE and effective post-gel shrinkage Results / handoff Free-release CLT curvature and separate corner spring-in estimate; not an automatic process-history handoff

Free CLT release from prescribed ply-local shrinkage/thermal eigenstrains. Corner spring-in is a separate uniform-strain estimate. Stress-free temperature and effective post-gel shrinkage need calibration. No tool friction, cure kinetics or viscoelastic restraint history.

**Formulations and study choices**

- Free-release eigenstrain & spring-in

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Fatigue residual properties

Structural models → Laminate mechanics → Fatigue → Residual properties

Inputs Modulus, independently fitted stiffness / strength retention laws, life and elapsed cycles Results / handoff Residual-property curves for the specified constant-amplitude calibration; saved laminate is unchanged

Prescribed power-law retention fitted to constant-amplitude tests at a fixed stress ratio, amplitude and temperature. Stiffness and strength have independent coefficients. S–N life alone cannot calibrate either. Does not modify the saved laminate.

**Formulations and study choices**

- Calibrated residual-property fatigue

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Cylinder buckling

Structural models → Cylinder models → Cylinder buckling

Inputs Thin specially orthotropic shell, radius, length, axial compression and prescribed knockdown Results / handoff Ideal / knocked-down Donnell axial buckling and governing mode; no pressure or postbuckling

Simply supported, thin, specially orthotropic cylinder under uniform axial compression. Discrete Donnell modes; prescribed knockdown factor explores imperfection sensitivity, not a prediction from measured imperfection amplitude. No pressure, torsion, postbuckling or strength pass.

**Formulations and study choices**

- Donnell cylinder · axial buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Uncertainty & sensitivity

Structural models → Uncertainty & sensitivity

Inputs Laminate, bounded modulus / thickness / angle variations, seed and axial load Results / handoff ABD axial-strain percentiles and signed correlations; not certified reliability

Seeded independent uniform sampling of shared modulus, ply-thickness and angle offsets. Recomputes laminate ABD for each sample. Bounds are assumptions, not measured distributions. Percentiles and sensitivity are exploratory, not reliability certification.

**Formulations and study choices**

- Seeded laminate uncertainty

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Normal-incidence laminate TMM

Models → Electromagnetics · RF → Normal-incidence laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

Coherent isotropic nonmagnetic layers between air half-spaces.

**Formulations and study choices**

- EM · Normal-incidence laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Oblique polarized laminate TMM

Models → Electromagnetics · RF → Oblique polarized laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

TE or TM waves; scalar isotropic layers, no polarization conversion.

**Formulations and study choices**

- EM · Oblique polarized laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ 1D transmission line matrix

Models → Electromagnetics · RF → 1D transmission line matrix

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflected and transmitted pulse histories and spectra; mesh and energy checks

Normal-incidence lossless delay-line mesh with pulse decay, energy and mesh-refinement safeguards. Explicit Run required; not a 3D solver.

### Formulations and study choices

- EM · 1D transmission line matrix

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ 1D Floquet–Bloch periodic layers

Models → Electromagnetics · RF → 1D Floquet–Bloch periodic layers

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Periodic-cell eigenvalues, folded Bloch phase and stop-band decay

Lossless isotropic A/B unit-cell eigenvalues, folded Bloch phase and stop-band attenuation at normal incidence. Not arbitrary-cell homogenization.

### Formulations and study choices

- EM · 1D Floquet–Bloch periodic layers

∑ Theory & assumptions

Guided exercise & two-layer workflow

Next workflow page 03.6 Cloud →

# 5 Turn ply definitions into laminate decisions

**Online chapter**

Connect stored or Micro-derived ply properties to a stacking sequence, then choose a compatible structural or separate analytical study.

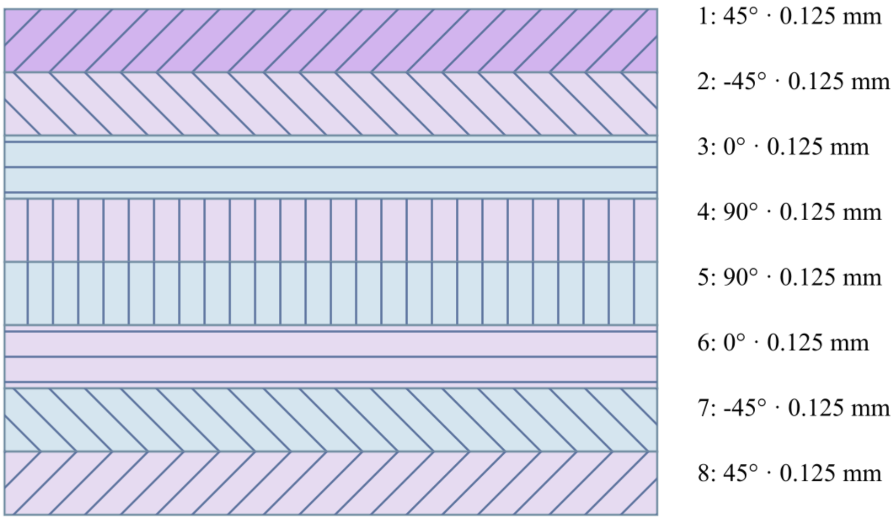
Inspect a ply stack

Angle pair ±θ: 45 °

Ply to resize

Selected ply thickness: 0.125 mm

8 plies · 1.000 mm total. Thickness is proportional in the section; line direction indicates angle, not a stress field.




Ply 1 at top · illustrative section ordering

[θ / −θ / 0 / 90 / 90 / 0 / −θ / θ]

03.3 / Workflow focus

Connected engineering record

## Ply stack

Set material references, angles and thicknesses. The stack defines laminate stiffness, mass and reference properties.

## CLT and FSDT

ABD properties support laminate response. Finite-plate studies select CLT or FSDT within their supported boundary and study limits; static plate bending requires FSDT.

## Failure and interfaces

Eligible CLT cases use the released failure criteria. Coupled delamination belongs to the supported layerwise section path with calibrated interfaces, not every plate solver.

## Separate analytical studies

Open-hole strength, linear-shear LaRC04 initiation, axial creep and uncertainty use the linked laminate reference state. They do not automatically inherit process or progressive-damage histories.

## Design exploration

Carpet maps and bounded optimization compare candidates. Apply a candidate and rerun the appropriate analysis; a saved result does not update itself.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

## Laminates released model connections

Expand a family for inputs, outputs, supported formulations, theory and an exercise. All model families

**∑ Plate · CLT & FSDT**

Structural models → Laminate mechanics · CLT / FSDT

Inputs Laminate stiffness, finite plate dimensions, supported edges and study choice Results / handoff FSDT static bending or selected buckling / modal results; not progressive damage

Choose a formulation and study. Buckling and modal can be requested together; static bending requires FSDT. These are reference-elastic studies, separate from coupled process or progressive failure.

**Formulations and study choices**

- CLT
- FSDT
- Static bending
- Modal
- Buckling
- Buckling and modal

∑ Theory & assumptions

Guided exercise & two-layer workflow

**∑ Membrane, bending & beam buckling**

Structural models → Laminate mechanics → Membrane, bending & beam

Inputs Laminate, compatible section and static or Euler load case Results / handoff Membrane / bending response or separate Euler buckling result

Geometry and the case determine the membrane or beam-test interpretation. Euler buckling requires a compatible beam section and a separate reference-elastic study; it is not a strength or local-buckling pass.

**Formulations and study choices**

- Linear static
- Linear static with failure indices
- Beam Euler buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Failure & envelope comparison

Structural models → Laminate mechanics → Failure criteria

Inputs Eligible CLT load case, strengths / strain limits and selected criterion Results / handoff First-ply envelopes or supported progressive ply-damage histories; criteria are not blended

One primary failure criterion per load. In Response → Failure, compare all eligible theories or a custom selection in the envelope controls. Each theory runs independently; criteria are not blended.

**Formulations and study choices**

- Maximum stress
- Maximum strain
- Tsai–Hill
- Tsai–Wu
- Hashin

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Failure equations

· Implemented Workbench methods

## ∑ D6641 · Compression coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

**Formulations and study choices**

- Virtual test · compression coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5379 / D7078 · Shear coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

**Formulations and study choices**

- Virtual test · nominal shear coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5528 · DCB opening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

**Formulations and study choices**

- Virtual test · DCB beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7905 · ENF sliding

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

**Formulations and study choices**

- Virtual test · ENF beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6671 · Mixed-mode fracture envelope

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

#### Formulations and study choices

- Virtual test · BK mixed-mode envelope

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5961 · Bearing / bypass screening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

#### Formulations and study choices

- Virtual test · bearing bypass screening

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6484 · Open-hole compression

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

**Formulations and study choices**

- Virtual test · measured open-hole compression

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6742 · Filled-hole comparison

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

**Formulations and study choices**

- Virtual test · measured filled-hole comparison

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7136 / D7137 · Impact & CAI assessment

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

**Formulations and study choices**

- Virtual test · measured impact and CAI

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Open-hole strength

Structural models → Laminate mechanics → Failure criteria → Open-hole strength

Inputs Specially orthotropic laminate, hole radius, unnotched strength and calibrated distances Results / handoff Point / average stress strength screening and radial stress profile

Infinite-width, specially orthotropic tension screening. Point and average stress distances must be calibrated independently for this laminate. Not compression, bearing or a joint allowable.

**Formulations and study choices**

- Whitney–Nuismer open-hole tension

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Creep & stress relaxation

Structural models → Laminate mechanics → Creep & stress relaxation

Inputs Laminate Ex, Prony fractions / times and held stress or strain at calibration temperature Results / handoff Separate axial creep and relaxation curves with time-refinement safeguards

Linear uniaxial response at the calibration temperature. Reference Ex is the instantaneous modulus. Three Maxwell branches; creep is solved from stress equilibrium, not the reciprocal relaxation modulus. No thermal shifting or nonlinear creep.

**Formulations and study choices**

- Generalized Maxwell · axial Prony

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ LaRC04 failure initiation

Structural models → Laminate mechanics → Failure criteria → LaRC04

Inputs Laminate, membrane / bending resultants and calibrated effective ply strengths Results / handoff Linear-shear LaRC04 initiation indices at ply faces; no progressive degradation

NASA LaRC04 linear-shear specialization, evaluated at both faces of every ply under membrane and bending loads. Supplied ply strengths are effective/in-situ values; no automatic thin-ply enhancement. Initiation only, not degradation or nonlinear-shear instability.

**Formulations and study choices**

- LaRC04 · linear shear

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Uncertainty & sensitivity

Structural models → Uncertainty & sensitivity

Inputs Laminate, bounded modulus / thickness / angle variations, seed and axial load Results / handoff ABD axial-strain percentiles and signed correlations; not certified reliability

Seeded independent uniform sampling of shared modulus, ply-thickness and angle offsets. Recomputes laminate ABD for each sample. Bounds are assumptions, not measured distributions. Percentiles and sensitivity are exploratory, not reliability certification.

**Formulations and study choices**

- Seeded laminate uncertainty

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Normal-incidence laminate TMM

Models → Electromagnetics · RF → Normal-incidence laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

Coherent isotropic nonmagnetic layers between air half-spaces.

**Formulations and study choices**

- EM · Normal-incidence laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Oblique polarized laminate TMM

Models → Electromagnetics · RF → Oblique polarized laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

TE or TM waves; scalar isotropic layers, no polarization conversion.

**Formulations and study choices**

- EM · Oblique polarized laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D transmission line matrix

Models → Electromagnetics · RF → 1D transmission line matrix

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflected and transmitted pulse histories and spectra; mesh and energy checks

Normal-incidence lossless delay-line mesh with pulse decay, energy and mesh-refinement safeguards. Explicit Run required; not a 3D solver.

**Formulations and study choices**

- EM · 1D transmission line matrix

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D Floquet–Bloch periodic layers

Models → Electromagnetics · RF → 1D Floquet–Bloch periodic layers

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Periodic-cell eigenvalues, folded Bloch phase and stop-band decay

Lossless isotropic A/B unit-cell eigenvalues, folded Bloch phase and stop-band attenuation at normal incidence. Not arbitrary-cell homogenization.

**Formulations and study choices**

- EM · 1D Floquet–Bloch periodic layers

∑ Theory & assumptions

Guided exercise & two-layer workflow

Next workflow page 03.4 Processing →

# 6 Build a trusted materials foundation

**Online chapter**

Organize source-aware constituents, vendor records, prepregs, adhesives, cores, sandwich systems, diffusion data, cure kinetics, crystallization kinetics, reaction heat, and process shrinkage into reusable engineering records.

Trace the selected input path

Ply property source

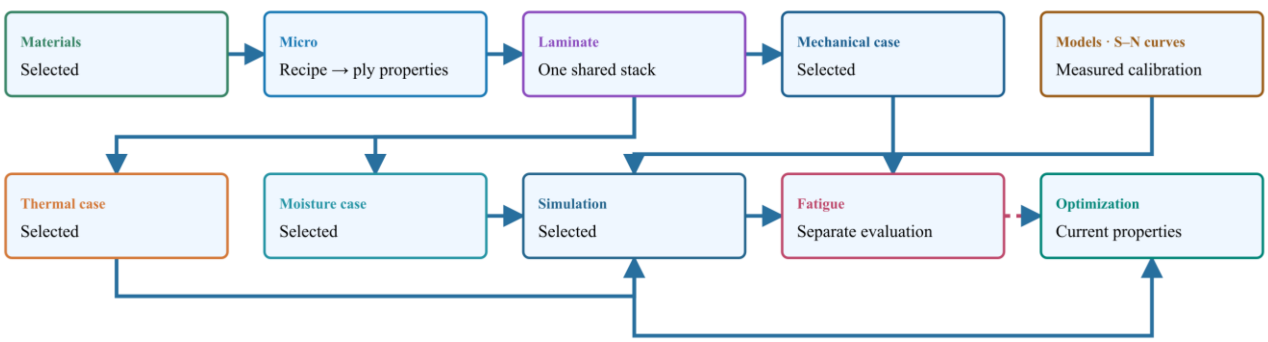
Include thermal analysis

Include moisture analysis

Include optional fatigue assessment

Stored ply properties bypass Micro. Mixed stacks keep both paths. Gray blocks are not selected. Geometry, process schedules and other model records are omitted here for clarity; a real run must include all required references.

Fatigue uses intact CLT endpoint stresses and measured S–N calibration. It is evaluated separately from Run and progressive failure. The dashed handoff is not active: optimization still uses current properties until a degradation law is supplied.




Dashed pink arrow: residual-fatigue study is separate—not an automatic property transfer.

Materials → Micro → Laminate.

03.1 / Workflow focus

Connected engineering record

## Source-aware constituents

Keep elastic, strength, density and transport data with their units, sources and calibration basis.

## Material models

Assign calibrated cure, crystallization, modulus or transport models through the material record. A model sitting in the tree does not contribute until it is linked.

## Measured or predicted plies

A laminate ply can use a stored material or linked Micro recipe. Check the resolved properties before selecting the structural study.

## Data handoff

Materials feed Micro and the linked laminate. Compatible transport studies evaluate the selected material laws; not every structural study includes processing.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

## Materials released model connections

Expand a family for inputs, outputs, supported formulations, theory and an exercise. All model families

**∑ Cure, crystallization & material transport**

Models → material-model folders · assigned through Materials

Inputs Calibrated kinetics, modulus or transport laws and material assignment Results / handoff Material laws consumed by compatible Micro or transport calculations

Independent model records can be linked together through material inputs. A saved model must be assigned to a material before it contributes to a simulation.

**Formulations and study choices**

- Kamal–Sourour autocatalytic
- Kamal–Sourour with diffusion control
- Nth-order Arrhenius
- CHILE (degree of cure)
- UV intensity-dependent cure
- Nakamura–Avrami
- Temperature-dependent tabular
- 1D Fickian diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cure kinetics

· Crystallization kinetics

Next workflow page 03.2 Micromechanics →

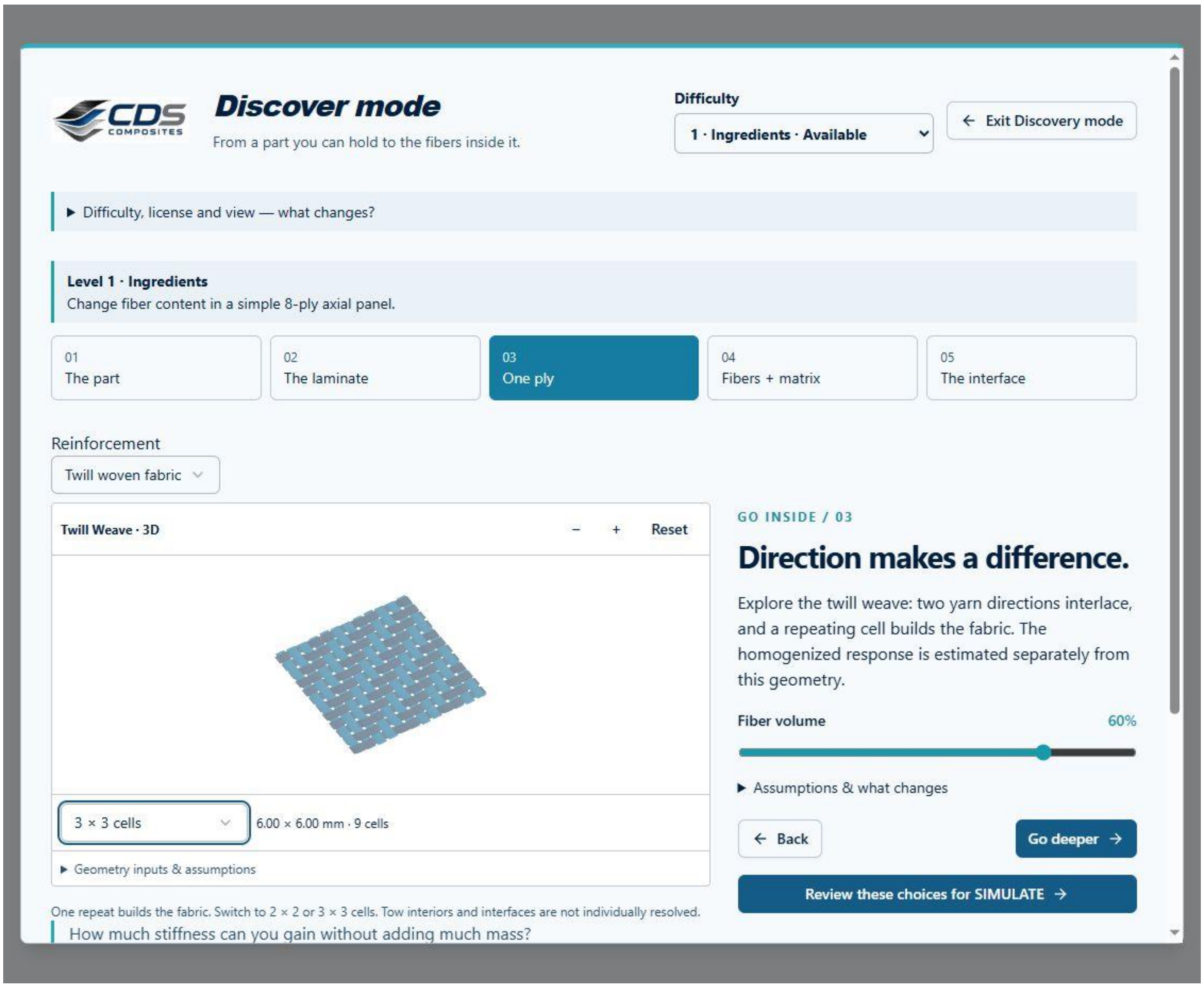
# 7 Translate constituents into effective material behavior

**Online chapter**

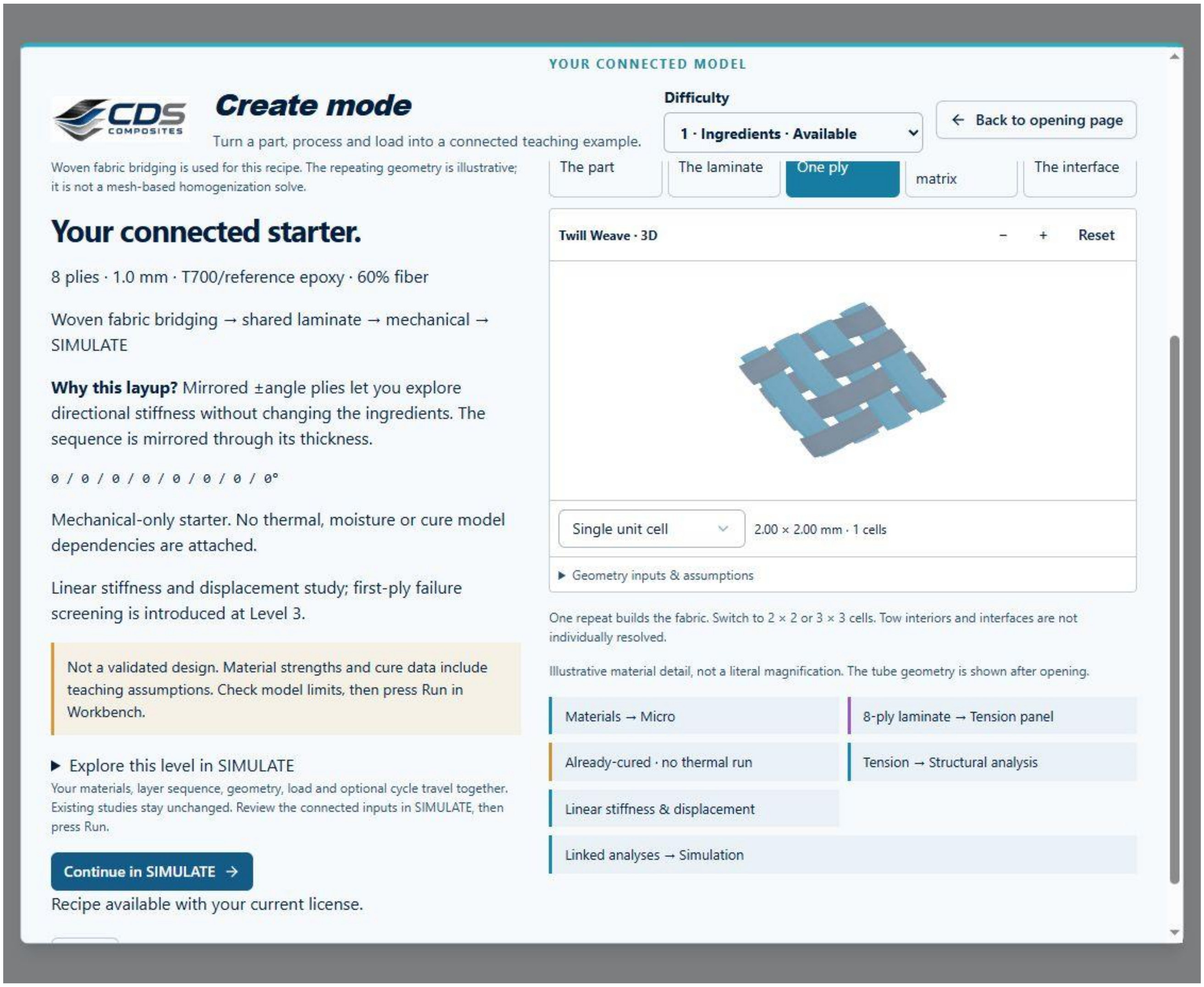
Choose a released architecture-compatible homogenization model, inspect its reference ply properties, and carry those properties into the laminate.

## One cell A whole fabric

Explore plain, twill and satin yarn surfaces in Micro, Live Stack, CREATE and DISCOVER. Switch between one repeat and 2 × 2 or 3 × 3 cells, then rotate and zoom. CREATE carries the selected weave and woven bridging model into SIMULATE, subject to your license.




DISCOVER: repeat a twill unit cell into a fabric patch.




CREATE: carry the weave into a connected laminate recipe.

Captured from the Workbench components in a local preview, September 17, 2026. Missing yarn dimensions are inferred and listed under Geometry inputs & assumptions. These are periodic surface illustrations—not measured textile CAD, solid exports or a mesh-based solver. Effective properties are calculated separately by the selected micromechanics model.

Explore fiber volume

Fiber volume: 60 %

Void volume: 2 %

Fiber modulus

230 GPa

Matrix modulus

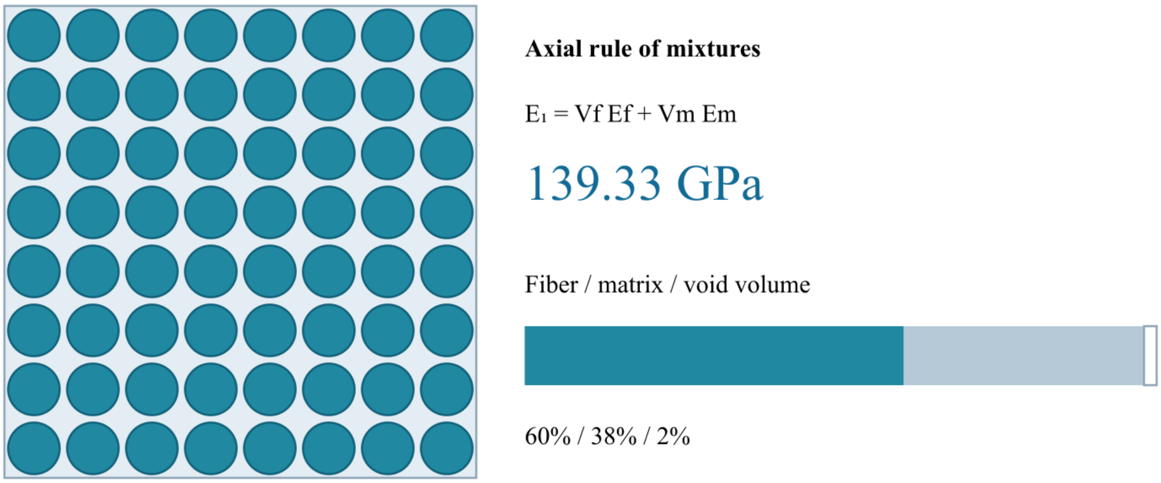
3.5 GPa

Matrix volume

38 %

Axial mixture estimate

139.33  GPa




Idealized UD section · fiber area follows Vf

Zero-stiffness void phase; no empirical void knockdown or transverse prediction.

03.2  / Workflow focus

Connected engineering record

## Compatible formulations

The Models browser lists rule-of-mixtures variants, Halpin–Tsai, Chamis, Mori–Tanaka, Hashin–Rosen, self-consistent, woven bridging and Cox elastic short-fiber choices. Architecture determines which choices are available.

## Short-fiber scope

Cox shear-lag elastic studies use prescribed geometry and orientation. The event-driven Henry–Pimenta RVE and its stochastic discontinuous-fiber failure route are not enabled in the hosted release.

## Ply-property handoff

The selected Micro recipe supplies reference properties to its linked plies. Shared material or Micro edits can change multiple laminate calculations.

## Explore and compare

Use an exercise or supported property sweep to compare model assumptions, constituent limits and sensitivity. Predicted strengths and teaching defaults are not qualified allowables.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

## Micromechanics released model connections

Expand a family for inputs, outputs, supported formulations, theory and an exercise. All model families

### ∑ Micromechanics

Models browser → Micromechanics · source: Micro

Inputs Constituents, architecture, fractions and calibrated modifiers Results / handoff Reference ply properties for each linked laminate ply

One compatible homogenization model per Micro recipe. Use separate recipes for comparisons; they are not combined in a single ply.

**Formulations and study choices**

- Halpin–Tsai
- Rule of mixtures
- Modified rule of mixtures
- Chamis
- Mori–Tanaka
- Hashin–Rosen
- Self-consistent scheme
- Woven fabric bridging
- Cox shear-lag elastic

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Wiener series and parallel

Models → Electromagnetics · RF → Wiener series and parallel

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Positive lossless dielectric bounds; complex directional estimates.

**Formulations and study choices**

- EM · Wiener series and parallel

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Looyenga / Landau–Lifshitz–Looyenga

Models → Electromagnetics · RF → Looyenga / Landau–Lifshitz–Looyenga

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

One cube-root mixing law, not two independent models.

**Formulations and study choices**

- EM · Looyenga / Landau–Lifshitz–Looyenga

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Maxwell–Garnett

Models → Electromagnetics · RF → Maxwell–Garnett

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Dilute subwavelength spherical inclusions in a host.

**Formulations and study choices**

- EM · Maxwell–Garnett

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Bruggeman symmetric EMT

Models → Electromagnetics · RF → Bruggeman symmetric EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Two positive-permittivity phases; no explicit contact network.

**Formulations and study choices**

- EM · Bruggeman symmetric EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM Mori–Tanaka

Models → Electromagnetics · RF → EM Mori–Tanaka

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis ellipsoidal field approximation.

**Formulations and study choices**

- EM · EM Mori–Tanaka

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM self-consistent

Models → Electromagnetics · RF → EM self-consistent

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis self-consistency; spherical case equals Bruggeman.

**Formulations and study choices**

- EM · EM self-consistent

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Differential effective medium

Models → Electromagnetics · RF → Differential effective medium

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Incremental mixing with time-step refinement check.

**Formulations and study choices**

- EM · Differential effective medium

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Coated sphere and interphase

Models → Electromagnetics · RF → Coated sphere and interphase

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Concentric subwavelength coated spheres; no dynamic Mie scattering.

**Formulations and study choices**

- EM · Coated sphere and interphase

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Generalized multiphase EMT

Models → Electromagnetics · RF → Generalized multiphase EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Spherical multiphase Bruggeman with convergence checks.

**Formulations and study choices**

- EM · Generalized multiphase EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

Next workflow page 03.3 Laminates →

# 8 Models you can use Connections you can follow

**Online chapter**

The released Workbench model set, grouped by engineering purpose. Open a family for its tree location, inputs, outputs, theory and guided exercise. Availability also depends on your license.

## 42 model families in the released Workbench

Choose a formulation in Models, edit its linked source record, connect required inputs in Simulation, then watch a quick workflow update or press Run. Tree nesting shows related methods—not permission to combine every method in one solve. A completed calculation is not a validated design pass.

**Live updates or Run?**

Small compatible workflows refresh after editing pauses, using the current connected materials, Micro, laminate and case inputs. Larger sampling, mode searches, mesh calculations and process histories require Run after upstream changes. Workbench also switches a workload to Run when measured solver time exceeds its live budget; it never reduces numerical accuracy to stay live.

The Solver control shows Live updates or Run required and can pause automatic updates. Hidden tabs do not start background refreshes. Superseded results are discarded, and all automatic runs retain the same model and license checks. Fast reference-state studies remain separate studies: live scheduling does not create new physical coupling.

### ∑ Micromechanics

Models browser → Micromechanics · source: Micro

Inputs Constituents, architecture, fractions and calibrated modifiers Results / handoff Reference ply properties for each linked laminate ply

One compatible homogenization model per Micro recipe. Use separate recipes for comparisons; they are not combined in a single ply.

**Formulations and study choices**

- Halpin–Tsai
- Rule of mixtures
- Modified rule of mixtures
- Chamis
- Mori–Tanaka
- Hashin–Rosen
- Self-consistent scheme
- Woven fabric bridging
- Cox shear-lag elastic

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cure, crystallization & material transport

Models → material-model folders · assigned through Materials

Inputs Calibrated kinetics, modulus or transport laws and material assignment Results / handoff Material laws consumed by compatible Micro or transport calculations

Independent model records can be linked together through material inputs. A saved model must be assigned to a material before it contributes to a simulation.

### Formulations and study choices

- Kamal–Sourour autocatalytic
- Kamal–Sourour with diffusion control
- Nth-order Arrhenius
- CHILE (degree of cure)
- UV intensity-dependent cure
- Nakamura–Avrami
- Temperature-dependent tabular
- 1D Fickian diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cure kinetics

· Crystallization kinetics

## ∑ Thermal transport

Models browser → Thermal transport · source: CASES / Thermal

Inputs Laminate transport properties, initial state and the thermal case's own surface cycle Results / handoff Temperature and supported polymer-state histories; mapped fields only when coupling is enabled

One transport formulation per thermal case. Select its laminate and configure its own initial conditions and surface cycle; pultrusion additionally requires a distance-based die schedule and pulling velocity.

### Formulations and study choices

- 1D transient heat transfer
- 1D steady-state heat transfer
- 1D pultrusion thermal cure

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Pultrusion exercise

· UV cure exercise

## ∑ Moisture transport

Models browser → Moisture transport · source: CASES / Moisture

Inputs Laminate diffusion properties, initial moisture and its own boundary schedule Results / handoff Moisture history and enabled swelling contribution

One formulation per moisture analysis. Thermal and moisture analyses can both be linked in Simulation; each needs its own boundary conditions.

**Formulations and study choices**

- 1D transient moisture diffusion
- 1D steady-state moisture diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Plate · CLT & FSDT

Structural models → Laminate mechanics · CLT / FSDT

Inputs Laminate stiffness, finite plate dimensions, supported edges and study choice Results / handoff FSDT static bending or selected buckling / modal results; not progressive damage

Choose a formulation and study. Buckling and modal can be requested together; static bending requires FSDT. These are reference-elastic studies, separate from coupled process or progressive failure.

**Formulations and study choices**

- CLT
- FSDT
- Static bending
- Modal
- Buckling
- Buckling and modal

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Cylinder

Structural models → Cylinder models

Inputs Laminate, cylinder dimensions and formulation-compatible pressure / axial loading Results / handoff Thin-wall membrane response or layerwise radial fields, with distinct assumptions

Choose one cylinder formulation per case record. Geometry and plies remain shared; thick-wall radial results exclude torsion and process strains.

**Formulations and study choices**

- Linear thin-wall membrane
- Layerwise thick-wall elasticity

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Layerwise thick-wall theory

## ∑ Membrane, bending & beam buckling

Structural models → Laminate mechanics → Membrane, bending & beam

Inputs Laminate, compatible section and static or Euler load case Results / handoff Membrane / bending response or separate Euler buckling result

Geometry and the case determine the membrane or beam-test interpretation. Euler buckling requires a compatible beam section and a separate reference-elastic study; it is not a strength or local-buckling pass.

**Formulations and study choices**

- Linear static
- Linear static with failure indices
- Beam Euler buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Layerwise sections, joints & delamination

Structural models → Layerwise sections & joints

Inputs Section or lap geometry, laminate, loads and calibrated interface properties Results / handoff x–z fields; coupled ply damage and delamination only for the supported layerwise plate path

Coupled delamination is available only for the layerwise Plate section and needs calibrated interface and ply properties. Lap-shear uses its separate joint geometry and perfectly bonded elastic formulation.

**Formulations and study choices**

- Layerwise x-z plane strain
- Single-lap x-z plane strain
- Coupled delamination growth

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cohesive interface theory

## ∑ Sandwich bending

Structural models → Sandwich bending

Inputs Faces, core, dimensions and three-point-bend load Results / handoff Deflection and separate face, core and nominal bond-shear screening

Dedicated sandwich screening. Check core, faces and nominal bond shear separately; peel, mixed-mode debonding and crack growth are not assessed.

**Formulations and study choices**

- Sandwich three-point bend

∑ Theory & assumptions

Guided exercise & two-layer workflow

**∑ Failure & envelope comparison**

Structural models → Laminate mechanics → Failure criteria

Inputs Eligible CLT load case, strengths / strain limits and selected criterion Results / handoff First-ply envelopes or supported progressive ply-damage histories; criteria are not blended

One primary failure criterion per load. In Response → Failure, compare all eligible theories or a custom selection in the envelope controls. Each theory runs independently; criteria are not blended.

**Formulations and study choices**

- Maximum stress
- Maximum strain
- Tsai–Hill
- Tsai–Wu
- Hashin

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Failure equations

· Implemented Workbench methods

**∑ Fatigue S–N**

Structural models → Laminate mechanics → Fatigue

Inputs Intact ply stresses, cyclic loads and measured S–N calibration Results / handoff Separate life assessment; no automatic laminate degradation

Select calibrated S–N curves for each material, direction and stress sign in Fatigue. Different sources can use different models. S–N life does not define residual stiffness or strength.

**Formulations and study choices**

- Kim–Zhang
- Sendeckyj
- Weibull S–N
- Kohout–Vechet
- Basquin

∑ Theory & assumptions

Starter load case · add calibrated fatigue

**∑ D6641 · Compression coupon**

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

Uniform small-strain compression using linked laminate Ex and thickness. Measured compressive strength supplies a screening ratio; fixture, tabs, buckling and failure evolution are not simulated.

#### Formulations and study choices

- Virtual test · compression coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5379 / D7078 · Shear coupon

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

Uniform nominal shear between notches using linked laminate Gxy and thickness. Not a notch/fixture stress field or nonlinear shear solution. Gauge length is the effective shear deformation length, not crosshead travel.

#### Formulations and study choices

- Virtual test · nominal shear coupon

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5528 · DCB opening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

Ideal Euler–Bernoulli DCB with equal homogeneous 0° arms, each half the linked laminate thickness. No root rotation, shear, large displacement or cohesive growth. Critical load is an initiation estimate from supplied GIc.

#### Formulations and study choices

- Virtual test · DCB beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7905 · ENF sliding

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

Ideal equal-arm, homogeneous 0° ENF beam; support span is twice the half-span. Crack must be shorter than the half-span. No shear/root correction or unstable crack growth. GIIc is supplied, not fitted automatically.

### Formulations and study choices

- Virtual test · ENF beam compliance

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ D6671 · Mixed-mode fracture envelope

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

Benzeggagh–Kenane envelope from calibrated GIc, GIIc and exponent. Supplied GI/GII are energy-release rates from a separate test reduction or analysis. This does not resolve the MMB lever fixture or propagate a crack.

### Formulations and study choices

- Virtual test · BK mixed-mode envelope

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ D5229 · Moisture uptake calibration

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

### Formulations and study choices

- Virtual test · Fickian uptake calibration

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5961 · Bearing / bypass screening

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

Single-pin nominal bearing, net-section and shear-out checks with independent measured allowables. Bypass tension is added to net-section load only. No contact, bolt preload, load redistribution or validated bearing–bypass interaction envelope.

**Formulations and study choices**

- Virtual test · bearing bypass screening

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6484 · Open-hole compression

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

Nominal gross/net stress and demand relative to measured open-hole compressive strength for this geometry and layup. This is test-data screening, not an uncalibrated notch-strength prediction. No local buckling or kink-band simulation.

**Formulations and study choices**

- Virtual test · measured open-hole compression

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D6742 · Filled-hole comparison

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

Compares user-measured open- and filled-hole compressive strengths using gross-section stress. Use matched layup, hole, environment and fastener condition. Filling a hole does not automatically recover strength; no fastener contact/preload model is applied.

**Formulations and study choices**

- Virtual test · measured filled-hole comparison

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D7136 / D7137 · Impact & CAI assessment

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

Incident energy from measured impact velocity; residual compressive strength from measured peak CAI force. Rebound energy estimates energy not returned to the striker, NOT damage energy. No impact/contact solver, damage-area prediction or energy-to-strength extrapolation.

**Formulations and study choices**

- Virtual test · measured impact and CAI

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Open-hole strength

Structural models → Laminate mechanics → Failure criteria → Open-hole strength

Inputs Specially orthotropic laminate, hole radius, unnotched strength and calibrated distances Results / handoff Point / average stress strength screening and radial stress profile

Infinite-width, specially orthotropic tension screening. Point and average stress distances must be calibrated independently for this laminate. Not compression, bearing or a joint allowable.

**Formulations and study choices**

- Whitney–Nuismer open-hole tension

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Creep & stress relaxation

Structural models → Laminate mechanics → Creep & stress relaxation

Inputs Laminate Ex, Prony fractions / times and held stress or strain at calibration temperature Results / handoff Separate axial creep and relaxation curves with time-refinement safeguards

Linear uniaxial response at the calibration temperature. Reference Ex is the instantaneous modulus. Three Maxwell branches; creep is solved from stress equilibrium, not the reciprocal relaxation modulus. No thermal shifting or nonlinear creep.

**Formulations and study choices**

- Generalized Maxwell · axial Prony

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Analytical bonded joint

Structural models → Layerwise sections & joints → Analytical bonded joint

Inputs Identical equivalent-elastic adherends, adhesive, overlap, width and tensile force Results / handoff Volkersen shear and Goland–Reissner shear / peel; no debond growth

Identical equivalent-elastic adherends, long free arms and a thin elastic adhesive. Compare shear-only Volkersen with eccentric single-lap shear and peel. Not a debonding, plasticity or strength calculation.

**Formulations and study choices**

- Volkersen & Goland–Reissner joint

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ LaRC04 failure initiation

Structural models → Laminate mechanics → Failure criteria → LaRC04

Inputs Laminate, membrane / bending resultants and calibrated effective ply strengths Results / handoff Linear-shear LaRC04 initiation indices at ply faces; no progressive degradation

NASA LaRC04 linear-shear specialization, evaluated at both faces of every ply under membrane and bending loads. Supplied ply strengths are effective/in-situ values; no automatic thin-ply enhancement. Initiation only, not degradation or nonlinear-shear instability.

**Formulations and study choices**

- LaRC04 · linear shear

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Tool-release shape

Structural models → Tool-release shape

Inputs Laminate and prescribed temperatures, CTE and effective post-gel shrinkage Results / handoff Free-release CLT curvature and separate corner spring-in estimate; not an automatic process-history handoff

Free CLT release from prescribed ply-local shrinkage/thermal eigenstrains. Corner spring-in is a separate uniform-strain estimate. Stress-free temperature and effective post-gel shrinkage need calibration. No tool friction, cure kinetics or viscoelastic restraint history.

**Formulations and study choices**

- Free-release eigenstrain & spring-in

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Fatigue residual properties

Structural models → Laminate mechanics → Fatigue → Residual properties

Inputs Modulus, independently fitted stiffness / strength retention laws, life and elapsed cycles Results / handoff Residual-property curves for the specified constant-amplitude calibration; saved laminate is unchanged

Prescribed power-law retention fitted to constant-amplitude tests at a fixed stress ratio, amplitude and temperature. Stiffness and strength have independent coefficients. S–N life alone cannot calibrate either. Does not modify the saved laminate.

**Formulations and study choices**

- Calibrated residual-property fatigue

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Cylinder buckling

Structural models → Cylinder models → Cylinder buckling

Inputs Thin specially orthotropic shell, radius, length, axial compression and prescribed knockdown Results / handoff Ideal / knocked-down Donnell axial buckling and governing mode; no pressure or postbuckling

Simply supported, thin, specially orthotropic cylinder under uniform axial compression. Discrete Donnell modes; prescribed knockdown factor explores imperfection sensitivity, not a prediction from measured imperfection amplitude. No pressure, torsion, postbuckling or strength pass.

**Formulations and study choices**

- Donnell cylinder · axial buckling

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Uncertainty & sensitivity

Structural models → Uncertainty & sensitivity

Inputs Laminate, bounded modulus / thickness / angle variations, seed and axial load Results / handoff ABD axial-strain percentiles and signed correlations; not certified reliability

Seeded independent uniform sampling of shared modulus, ply-thickness and angle offsets. Recomputes laminate ABD for each sample. Bounds are assumptions, not measured distributions. Percentiles and sensitivity are exploratory, not reliability certification.

**Formulations and study choices**

- Seeded laminate uncertainty

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Wiener series and parallel

Models → Electromagnetics · RF → Wiener series and parallel

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Positive lossless dielectric bounds; complex directional estimates.

**Formulations and study choices**

- EM · Wiener series and parallel

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Looyenga / Landau–Lifshitz–Looyenga

Models → Electromagnetics · RF → Looyenga / Landau–Lifshitz–Looyenga

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

One cube-root mixing law, not two independent models.

**Formulations and study choices**

- EM · Looyenga / Landau–Lifshitz–Looyenga

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Maxwell–Garnett

Models → Electromagnetics · RF → Maxwell–Garnett

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Dilute subwavelength spherical inclusions in a host.

**Formulations and study choices**

- EM · Maxwell–Garnett

∑ Theory & assumptions

Guided exercise & two-layer workflow

## ∑ Normal-incidence laminate TMM

Models → Electromagnetics · RF → Normal-incidence laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

Coherent isotropic nonmagnetic layers between air half-spaces.

**Formulations and study choices**

- EM · Normal-incidence laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Bruggeman symmetric EMT

Models → Electromagnetics · RF → Bruggeman symmetric EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Two positive-permittivity phases; no explicit contact network.

**Formulations and study choices**

- EM · Bruggeman symmetric EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM Mori–Tanaka

Models → Electromagnetics · RF → EM Mori–Tanaka

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis ellipsoidal field approximation.

**Formulations and study choices**

- EM · EM Mori–Tanaka

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ EM self-consistent

Models → Electromagnetics · RF → EM self-consistent

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Scalar principal-axis self-consistency; spherical case equals Bruggeman.

**Formulations and study choices**

- EM · EM self-consistent

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Differential effective medium

Models → Electromagnetics · RF → Differential effective medium

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Incremental mixing with time-step refinement check.

**Formulations and study choices**

- EM · Differential effective medium

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Coated sphere and interphase

Models → Electromagnetics · RF → Coated sphere and interphase

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Concentric subwavelength coated spheres; no dynamic Mie scattering.

**Formulations and study choices**

- EM · Coated sphere and interphase

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Generalized multiphase EMT

Models → Electromagnetics · RF → Generalized multiphase EMT

Inputs Explicit host/inclusion electrical properties and fractions Results / handoff Effective permittivity; manual handoff to an RF layer, not an automatic mechanical-property update

Spherical multiphase Bruggeman with convergence checks.

**Formulations and study choices**

- EM · Generalized multiphase EMT

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Oblique polarized laminate TMM

Models → Electromagnetics · RF → Oblique polarized laminate TMM

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization Results / handoff Reflection, transmission, absorption and shielding spectra; no mechanical coupling

TE or TM waves; scalar isotropic layers, no polarization conversion.

**Formulations and study choices**

- EM · Oblique polarized laminate TMM

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D transmission line matrix

Models → Electromagnetics · RF → 1D transmission line matrix

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Reflected and transmitted pulse histories and spectra; mesh and energy checks

Normal-incidence lossless delay-line mesh with pulse decay, energy and mesh-refinement safeguards. Explicit Run required; not a 3D solver.

**Formulations and study choices**

- EM · 1D transmission line matrix

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ 1D Floquet–Bloch periodic layers

Models → Electromagnetics · RF → 1D Floquet–Bloch periodic layers

Inputs Explicit dielectric A/B layers, thicknesses, repetition, frequency and supported polarization
Results / handoff Periodic-cell eigenvalues, folded Bloch phase and stop-band decay

Lossless isotropic A/B unit-cell eigenvalues, folded Bloch phase and stop-band attenuation at normal incidence. Not arbitrary-cell homogenization.

**Formulations and study choices**

- EM · 1D Floquet–Bloch periodic layers

∑ Theory & assumptions

Guided exercise & two-layer workflow

**Reference theory versus released functionality**

The wider theory library also describes research and compiled-solver formulations. Event-driven Henry–Pimenta RVE, stochastic discontinuous-fiber failure, Puck, nonlinear-shear LaRC04, impact and general 3D finite-element analysis are not selectable hosted Workbench models. Cox elastic short-fiber homogenization and the separate linear-shear LaRC04 study are available within their stated limits.

Reference-state studies run separately from coupled process or progressive analyses. Residual-fatigue results do not automatically update optimization properties. Tool release uses prescribed eigenstrains rather than importing a cure history.

# 9 Connect design intent to process behavior

**Online chapter**

Solve steady-state or transient through-thickness process response before structural analysis, using effective ply transport properties, independent top and bottom schedules, cure exotherm, cure-dependent modulus, polymer kinetics, water uptake or release, and process-cycle optimization.

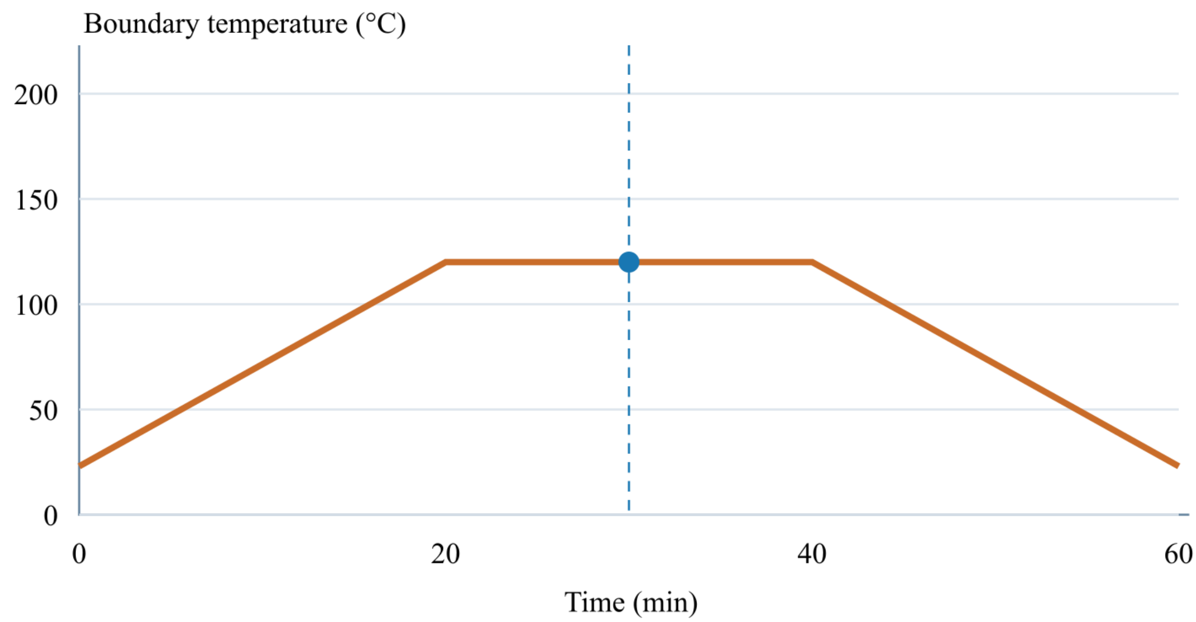
Read time and travel distance

Boundary peak: 120 °C

Pull speed: 10 mm/min

Time cursor: 30 min

Show length instead of time




Cursor: 30 min · 300 mm · 120.0 °C

03.4 / Workflow focus

Connected engineering record

## Independent boundary schedules

Thermal and moisture loads each need compatible material properties, a laminate, initial conditions and their own surface schedule.

## Thermal and moisture formulations

Choose the steady or transient transport model for the study. Transient histories resolve the supported one-dimensional through-thickness problem.

## Cure crystallization and UV

Assigned calibrated material laws govern supported polymer-state calculations. UV cure needs its exposure inputs; pultrusion needs the distance/time relationship and pulling speed.

## Supported coupling

A process schedule alone is not a solved history. Only compatible coupled analyses consume recovered environmental fields; reference-elastic studies remain separate.

## Tool-release shape

The separate free-release CLT study uses prescribed temperatures and effective shrinkage. It is not a tool-contact simulation or an automatic transfer of the thermal cure history.

## Process optimization

Compare bounded cycle candidates under supported objectives, save the evidence and rerun the selected candidate.

Workbench availability: released models, inputs and compatible study paths . The wider theory library includes reference formulations not available in every Workbench solve.

Use this workflow in Workbench: interactive Blocks, record selections and connection controls →

# Processing released model connections

Expand a family for inputs, outputs, supported formulations, theory and an exercise. All model families

**∑ Cure, crystallization & material transport**

Models → material-model folders · assigned through Materials

Inputs Calibrated kinetics, modulus or transport laws and material assignment Results / handoff Material laws consumed by compatible Micro or transport calculations

Independent model records can be linked together through material inputs. A saved model must be assigned to a material before it contributes to a simulation.

**Formulations and study choices**

- Kamal–Sourour autocatalytic
- Kamal–Sourour with diffusion control
- Nth-order Arrhenius
- CHILE (degree of cure)
- UV intensity-dependent cure
- Nakamura–Avrami
- Temperature-dependent tabular
- 1D Fickian diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Cure kinetics

· Crystallization kinetics

### ∑ Thermal transport

Models browser → Thermal transport · source: CASES / Thermal

Inputs Laminate transport properties, initial state and the thermal case's own surface cycle Results / handoff Temperature and supported polymer-state histories; mapped fields only when coupling is enabled

One transport formulation per thermal case. Select its laminate and configure its own initial conditions and surface cycle; pultrusion additionally requires a distance-based die schedule and pulling velocity.

**Formulations and study choices**

- 1D transient heat transfer
- 1D steady-state heat transfer
- 1D pultrusion thermal cure

∑ Theory & assumptions

Guided exercise & two-layer workflow

· Pultrusion exercise

· UV cure exercise

### ∑ Moisture transport

Models browser → Moisture transport · source: CASES / Moisture

Inputs Laminate diffusion properties, initial moisture and its own boundary schedule Results / handoff Moisture history and enabled swelling contribution

One formulation per moisture analysis. Thermal and moisture analyses can both be linked in Simulation; each needs its own boundary conditions.

**Formulations and study choices**

- 1D transient moisture diffusion
- 1D steady-state moisture diffusion

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ D5229 · Moisture uptake calibration

Models → Structural models → ASTM · Virtual Test Lab

Inputs Linked laminate and explicit specimen, load or measured calibration inputs Results / handoff Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

Homogeneous slab, initially dry, both faces held at equilibrium moisture. Fits diffusivity from two early uptake measurements (both ≤50% saturation) using the square-root-time approximation. Edge ingress and temperature dependence are excluded. Does not overwrite material properties.

**Formulations and study choices**

- Virtual test · Fickian uptake calibration

∑ Theory & assumptions

Guided exercise & two-layer workflow

### ∑ Tool-release shape

Structural models → Tool-release shape

Inputs Laminate and prescribed temperatures, CTE and effective post-gel shrinkage Results / handoff Free-release CLT curvature and separate corner spring-in estimate; not an automatic process-history handoff

Free CLT release from prescribed ply-local shrinkage/thermal eigenstrains. Corner spring-in is a separate uniform-strain estimate. Stress-free temperature and effective post-gel shrinkage need calibration. No tool friction, cure kinetics or viscoelastic restraint history.

**Formulations and study choices**

- Free-release eigenstrain & spring-in

∑ Theory & assumptions

Guided exercise & two-layer workflow

Next workflow page 03.5 Design →