DARWIN® 7.0 Release Notes

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Southwest Research Institute®

Summary of New Capabilities

DARWIN 7.0 includes the following new features:

- Automatic Generation of Optimum Fracture Mechanics Models
- New Stress Intensity Factor Solution for Through-edge Crack in a Variable Thickness Plate
- Enhanced Stress Intensity Factor Solutions for Embedded Crack in Plate
- Bivariant Shakedown Module
- Kt for Turned Surfaces
- Surface Area of Blade Slots
- User Specification of Manufacturing Process Credits
- FAA Hole Feature Surface Damage Report Form
- ABAQUS Result File Translator in FE2NEU
- Named Components in FE2NEU
- New Configuration for Display of GUI Warning Messages
- General Enhancements
    - Crack Growth Life Interpolation
    - Treatment of Large Results Files
    - Stress Gradient Search Enhancement

Automatic Generation of Optimum Fracture Mechanics Models

The DARWIN GUI permits analysts to quickly construct fracture models from finite element models. However, the quality of the resulting fracture model still depends on the skill and judgment of the analyst, which can be problematic if he or she has limited experience or formal training in fracture mechanics. Furthermore, integrity analysis of components in which fatigue cracks can form at material anomalies located anywhere in the volume of the component may require the construction of large numbers of fracture models. Even with the GUI tools, this can still be a time-consuming (expensive) process.

An alternative scheme has been developed that automatically determines (without user input) the orientation, size, and stress input for a fracture model that will produce accurate life results, given only the 2D model (or slice) and the initial crack location. The new automatic fracture model generation algorithm emulates the judgment of an experienced user by orienting and sizing a rectangular plate fracture model to reflect the actual component boundaries in the vicinity of a surface, corner, or embedded crack. Special algorithms accommodate curved boundaries and non-normal corners. Plate models for embedded cracks near external boundaries are oriented to accommodate automatic transition to surface cracks. Embedded plate models are otherwise oriented to capture the most significant univariant stress gradient near the crack. The final plate model is not always fully contained within the component boundaries, since this may be excessively conservative, but plate width and thickness are always sized to preserve appropriate ligaments along the primary axes of the crack, and to prevent the crack itself from going outside the actual component boundaries. The algorithm estimates the critical crack size (based on stresses from user-specified time steps) as an aid to making some sizing decisions, but requires no fatigue crack growth calculations, and so a large number of fracture models can be constructed in very little computational time.

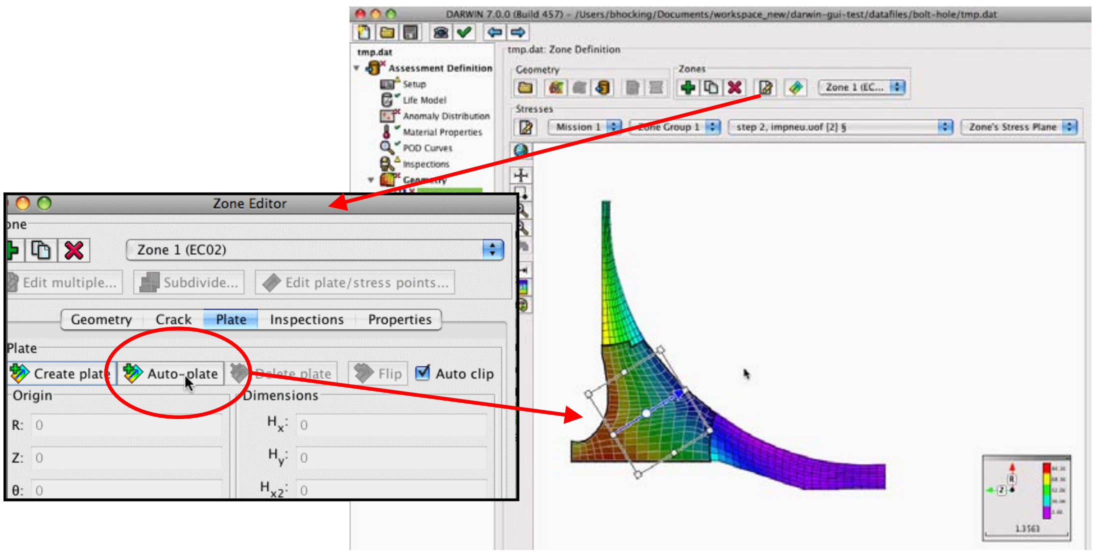
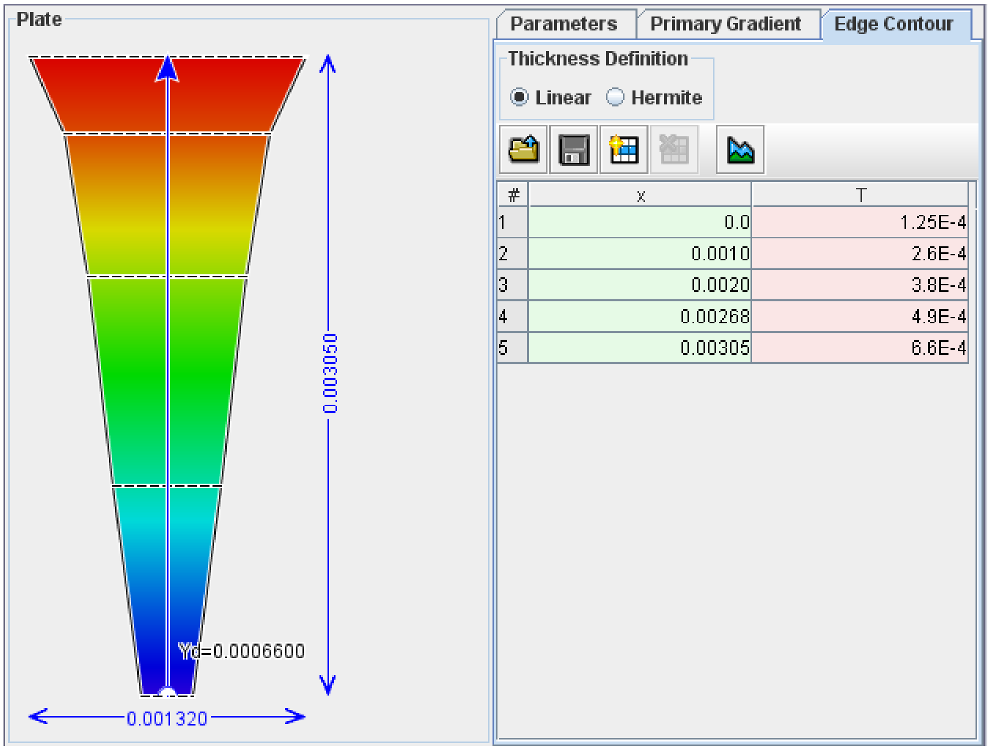


Figure 1: Automatic generation of optimum fracture mechanics geometry models.

New Stress Intensity Factor Solution for Through-Edge Crack in a Variable Thickness Plate

A new stress intensity factor (SIF) solution for a through-edge crack in a variable thickness plate, denoted TC15, has been implemented in DARWIN 7.0. TC15 is the first SIF solution implemented in DARWIN that does not employ a rectangular plate geometry model. The DARWIN GUI allows the User to use the mouse to specify a piecewise linear thickness variation in the model, based on interrogation of the underlying finite element model, and to immediately visualize the resulting fracture model. The linear segments can vary in number and length. TC15 is an approximate univariant weight function solution based on the TC12 edge crack SIF solution and energy considerations. The thickness variation must be symmetric about the center line of the plate, and step changes in thickness are not currently permitted.



#	x	T
1	0.0	1.25E-4
2	0.0010	2.6E-4
3	0.0020	3.8E-4
4	0.00268	4.9E-4
5	0.00305	6.6E-4

Figure 2: TC15 through-edge crack in variable thickness plate model.

Enhanced Stress Intensity Factor Solutions for Embedded Crack in Plate

Two new weight function stress intensity factor (SIF) solutions for an embedded crack in a plate have been implemented in DARWIN 7.0. The solutions are designated as EC04 for an embedded crack subjected to bivariant stresses and EC05 for the crack subjected to univariant stresses. The two SIF solutions use the same reference solutions generated by the FADD3D computer program. A univariant embedded crack SIF solution (EC02) was previously available in DARWIN; the new univariant solution EC05 was developed primarily to preserve quantitative consistency with the bivariant EC04 solution when the stress fields are univariant. EC04 and EC05 also provide a broader geometry range than EC02, because the embedded crack can approach very close to two adjacent free surfaces (EC02 could only approach very close to a single free surface). Limited studies to date have indicated that EC02 and EC05 give similar results. The old EC02 solution will remain available in DARWIN in order to facilitate comparisons and the use of input decks from previous DARWIN versions. However, EC02 will be phased out after DARWIN 7.0.

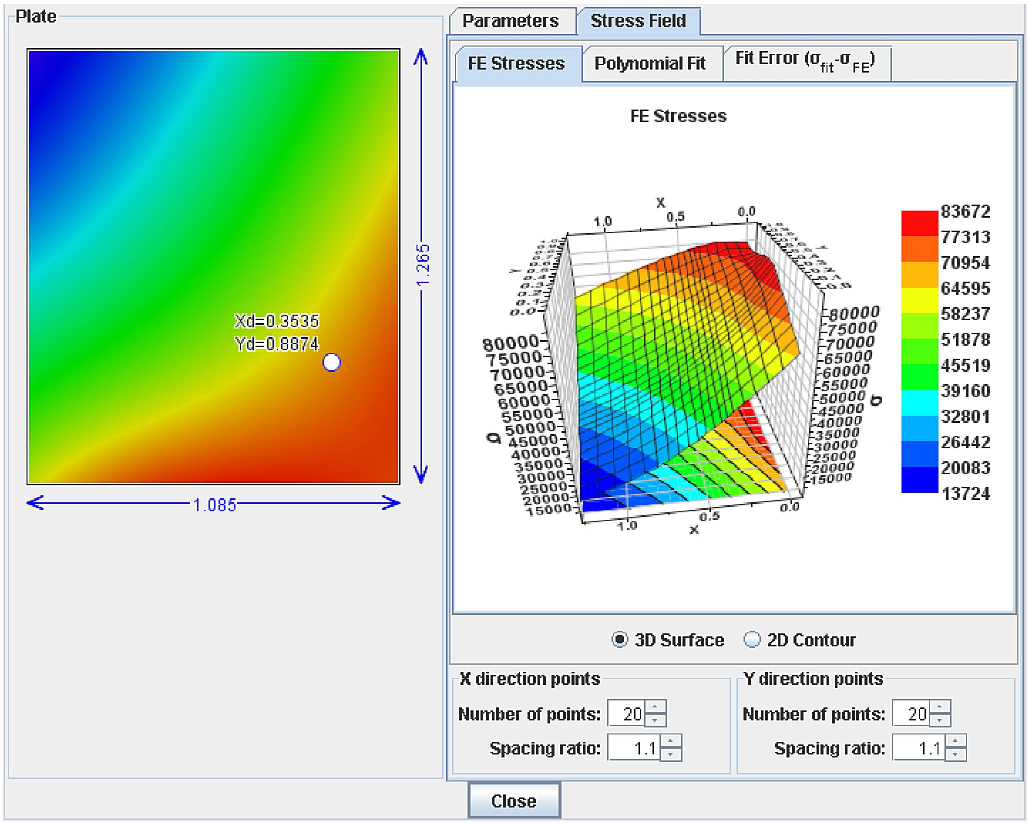


Figure 3. Selected DARWIN GUI stress visualization capabilities for the new bivariant embedded crack solution, EC04.

Bivariant Shakedown Module

A bivariant shakedown module has been implemented in DARWIN 7.0. Shakedown models provide an approximate calculation of the actual elastic-plastic stress distribution when elastically-calculated local stresses exceed the yield strength, and the resulting plastic deformation causes local stress relaxation and redistribution. DARWIN has included a univariant shakedown module for many years, and this was adequate for univariant weight function SIF solutions. However, the recent development and implementation of bivariant weight function SIF solutions (CC09, CC10, SC19, and now EC04) necessitated the development and implementation of a corresponding bivariant shakedown module that could accommodate stress distributions with arbitrary variations in all directions on the crack plane. The new methodology is for proportional loading and accommodates a single shakedown event occurring at maximum load. Both forces and moments are preserved in the calculation.

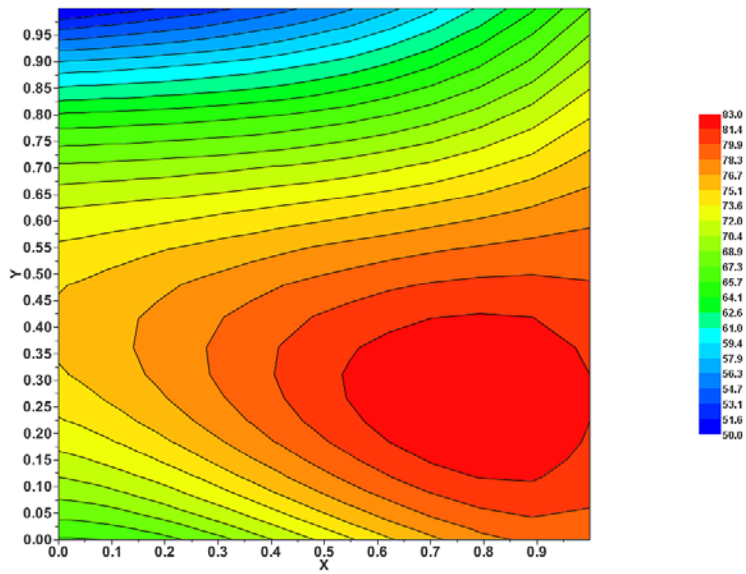


Figure 4. GUI visualization of bivariant shakedown stress field results.

Kt for Turned Surfaces

A new capability was implemented for assessment of turned surfaces near stress concentrations. It is based on existing DARWIN features for treatment of turned surfaces (2D Surface Damage Analysis mode) and stress concentration (Kt) effects (General Inherent Analysis mode). As shown in the following figure, the new capability enables the User to define Kt regions near stress concentrations such as holes. The Kt gradient associated with the Kt region is automatically applied to crack growth computations for zones with stress gradients that fall within the Kt region.

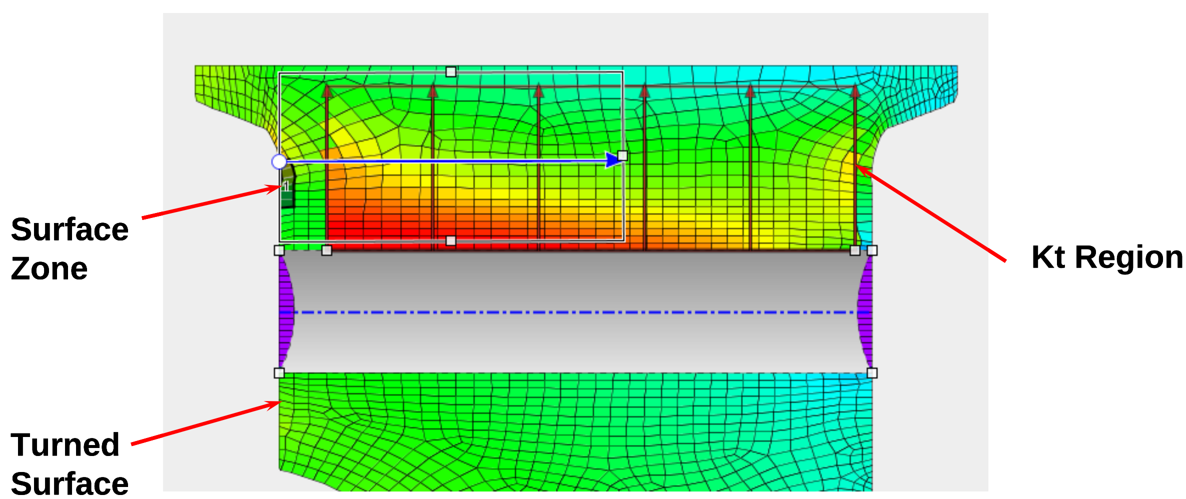
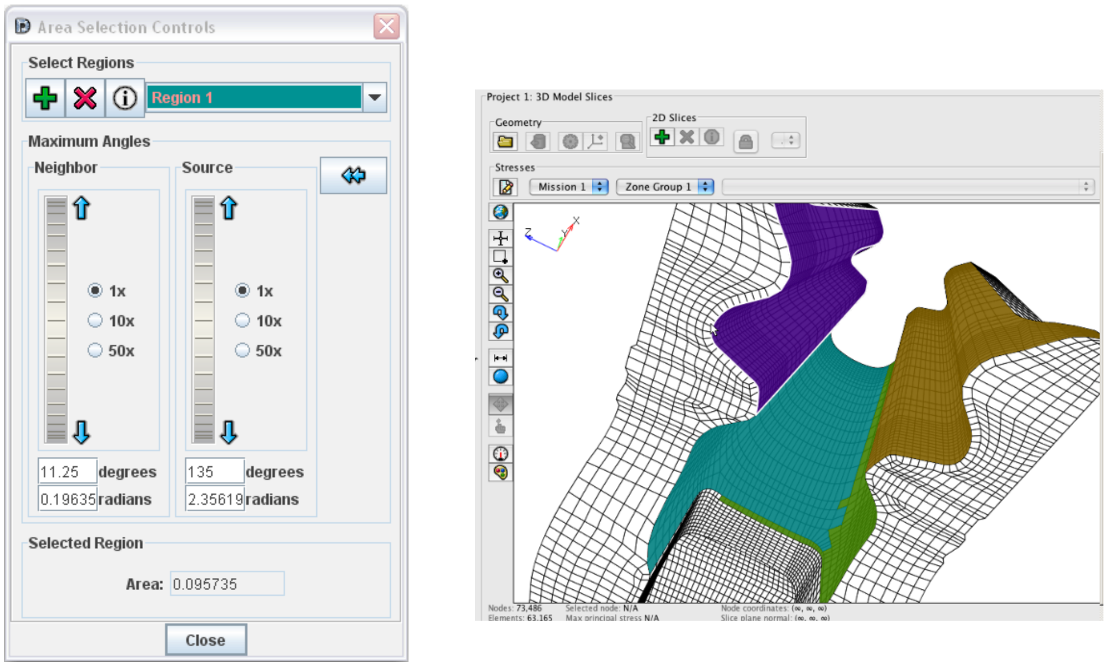


Figure 5: New capability for assessment of turned surfaces near stress concentrations.

Surface Area of Blade Slots

A new capability has been developed for surface damage assessment of blade slots to assist the User in the quantification of the surface area for a blade slot. It includes new GUI controls that allow the User to specify and visualize the finite element faces in a 3D finite element model associated with blade slot features.



(a) (b)

Figure 6: New capability for quantification of blade slot surface area: (a) GUI controls allow the User to specify the finite element faces that are included in the assessment, (b) GUI visualization of blade slot surface areas.

User Specification of Manufacturing Process Credits

FAA Advisory Circular AC33.70-2 describes a number of manufacturing credits associated with applicable process controls that can be applied to potentially reduce the fracture risk of a component. A new GUI capability was implemented to enable User specification of these manufacturing process credits for surface damage assessments. Risk results associated with the use of manufacturing credits are included in the FAA Bolt Hole Surface Damage Report Form.

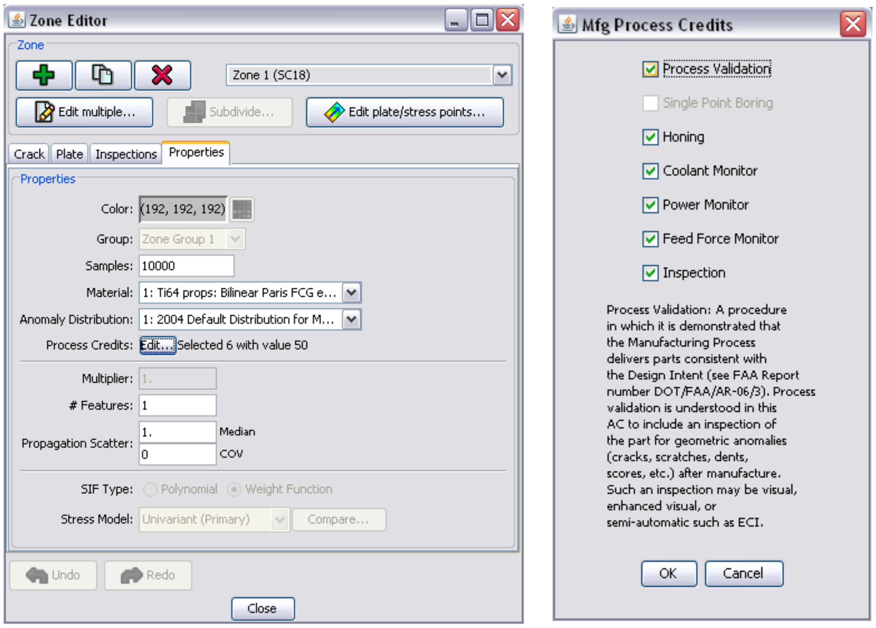
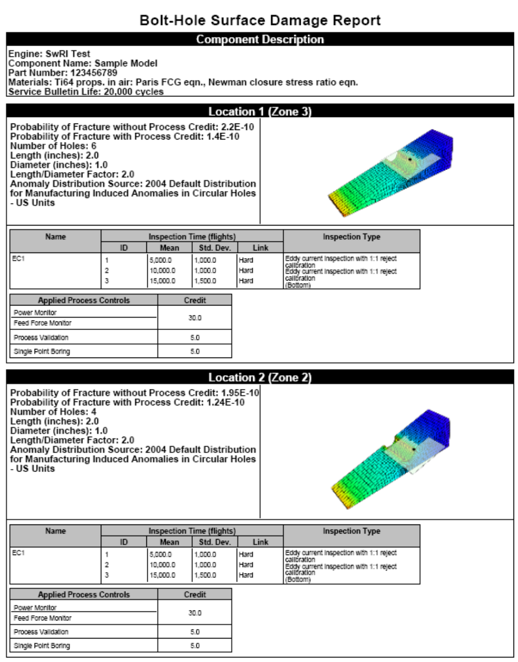


Figure 7: New GUI capability for user specification of manufacturing process credits.

FAA Hole Feature Surface Damage Report Form

A new reporting capability for the surface damage assessment of hole features is available. The content and format of the new form (Figure 8) includes the essential assessment data that would be applicable for an FAA review.



Bolt-Hole Surface Damage Report

Component Description

Engine: SwRI Test
Component Name: Sample Model
Part Number: 123456789
Materials: Ti64 props. in air: Paris FCG eqn., Newman closure stress ratio eqn.
Service Bulletin Life: 20,000 cycles

Location 1 (Zone 3)

Probability of Fracture without Process Credit: 2.2E-10
Probability of Fracture with Process Credit: 1.4E-10
Number of Holes: 6
Length (inches): 2.0
Diameter (inches): 1.0
Length/Diameter Factor: 2.0
Anomaly Distribution Source: 2004 Default Distribution for Manufacturing Induced Anomalies in Circular Holes - US Units

Name	Inspection Time (flights)				Inspection Type
	ID	Mean	Std. Dev.	Link	
EC1	1 2 3	5,000.0 10,000.0 15,000.0	1,000.0 1,000.0 1,500.0	Hard Hard Hard	Eddy current inspection with 1:1 reject calibration Eddy current inspection with 1:1 reject calibration (Bottom)

Applied Process Controls	Credit
Power Monitor Feed Force Monitor	30.0
Process Validation	5.0
Single Point Boring	5.0

Location 2 (Zone 2)

Probability of Fracture without Process Credit: 1.95E-10
Probability of Fracture with Process Credit: 1.24E-10
Number of Holes: 4
Length (inches): 2.0
Diameter (inches): 1.0
Length/Diameter Factor: 2.0
Anomaly Distribution Source: 2004 Default Distribution for Manufacturing Induced Anomalies in Circular Holes - US Units

Name	Inspection Time (flights)				Inspection Type
	ID	Mean	Std. Dev.	Link	
EC1	1 2 3	5,000.0 10,000.0 15,000.0	1,000.0 1,000.0 1,500.0	Hard Hard Hard	Eddy current inspection with 1:1 reject calibration Eddy current inspection with 1:1 reject calibration (Bottom)

Applied Process Controls	Credit
Power Monitor Feed Force Monitor	30.0
Process Validation	5.0
Single Point Boring	5.0

Figure 8: New DARWIN FAA Hole Feature Surface Damage Report Form.

ABAQUS Result File Translator in FE2NEU

The finite element model refinement module FE2NEU was enhanced to support the translation of ABAQUS result database (*.odb) files to the DARWIN neutral file format. The new ABAQUS translator has been verified on the standard element types supported by DARWIN, including 2D quadrilateral, 3D tetrahedron, and brick-type elements. Other degenerate element types such as 6-node and 15-node 3D prism elements are supported, but have not been fully verified.

Table 1: Element Types Supported by ABAQUS Translator

ABAQUS Types	SIESTA Types	Verified Types
CAX3*	EL2D	CAX3
CAX4*	EL2D	CAX4I
CAX6*	PE2D	
CAX8*	PE2D	CAX8R
C3D8*	BRI8	C3D8R
C3D10*	TETS N10	C3D10
C3D15*	VANS N20	
C3D20*	VANS N20	C3D20

* stands for I, R, M, H element types and their combinations

Named Components in FE2NEU

FE2NEU provides element filtering capabilities based on material, element ID, and load step numbering, as well as element type. In DARWIN 7.0, FE2NEU was enhanced (Figure 9) to allow the User to filter out finite elements based on element groupings called Named Components, a feature associated with ANSYS finite element models.

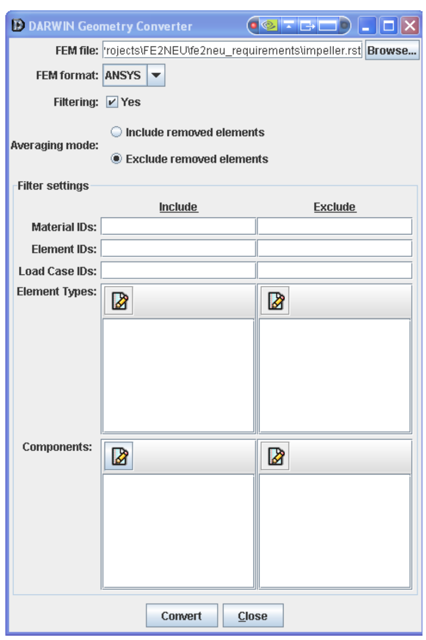


Figure 9: FE2NEU was enhanced to allow the User to filter out finite elements based on Named Components associated with ANSYS finite element models.

New Configuration for Display of GUI Warning Messages

The DARWIN GUI includes a feature that checks for errors in the input file and provides a list of all error/warning messages. Users may wish to avoid the display of repeated trivial warning messages, since these can sometimes occur in such large numbers that truly critical warnings go unnoticed. To address this issue, a warning filter has been implemented that allows the User to specify the warnings that will appear in the GUI error/warning report.

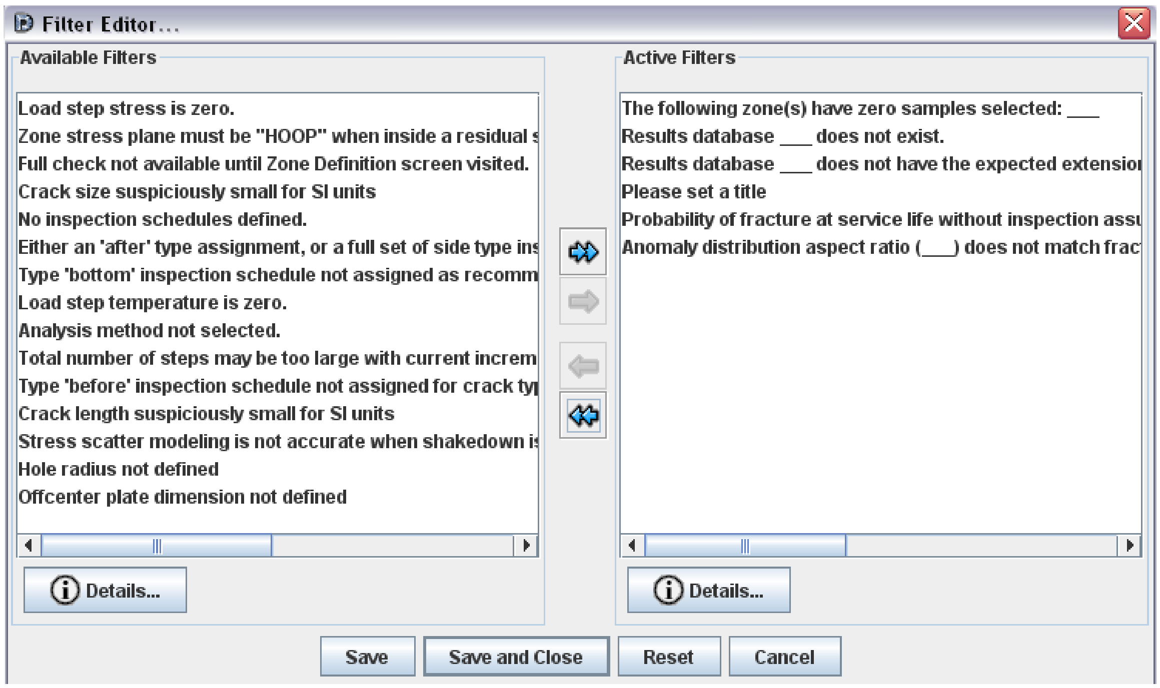


Figure 10: Warning message filter associated with new configuration for display of GUI warning messages.

General Enhancements

Crack Growth Life Interpolation

The DARWIN Flight_Life crack growth life integration algorithm determines the optimal crack growth life cycle increments (or integration steps/points) to obtain crack propagation life efficiently for a specified precision. The optimal cycle increments usually do not contain all cycle values that are needed for User-specified result printing and inspection schedules. Previously, the cycle values at User-specified print/inspection intervals were added to the integration points of the Flight_Life method to obtain results at these cycles. Consequently, the Flight_Life results were influenced by User-specified print/inspection intervals because the numerical integration result was dependent on the number of integration steps.

A new interpolation method has been implemented to address this issue. The new method utilizes a non-intrusive approach consisting of two steps. First, the crack growth life is calculated based on the optimal cycle increments determined by the Flight_Life integration algorithm. Then the results at User-specified print/inspection intervals are obtained from an interpolation of crack growth life results as shown in the figure below. Consequently, the results are more consistent because the integration steps are not affected by the User-specified print/inspection intervals.

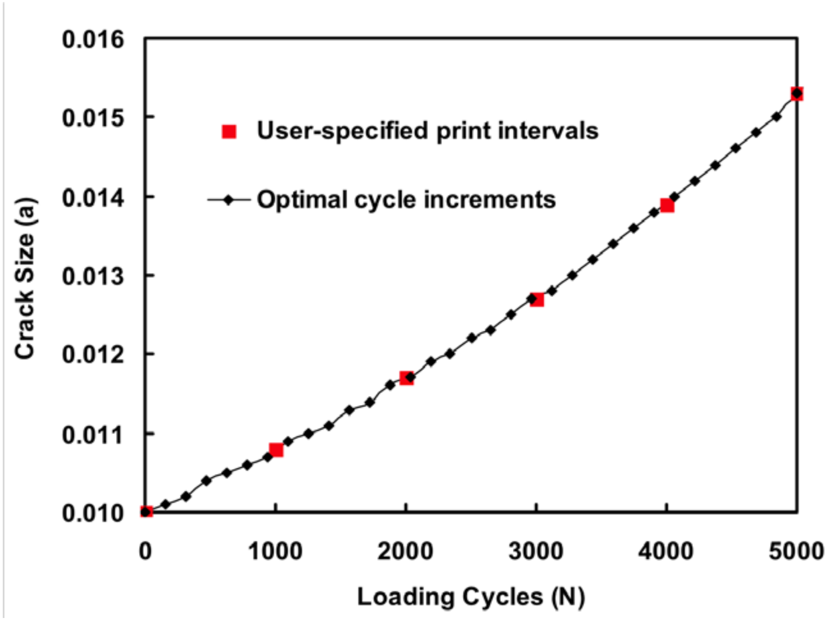


Figure 11: Flight_Life intervals based on optimal cycle increments and the interpolated results at User-specified print intervals

Treatment of Large Results Files

A new output verbosity control has been implemented in DARWIN to allow the User to select specific portions of results to be written to output files. By controlling the verbosity of the OUT and DDB result output files, extremely large models can be reduced to more manageable sizes. Furthermore, intermediate result information that a user may not be interested in can be suppressed to conserve disk space.

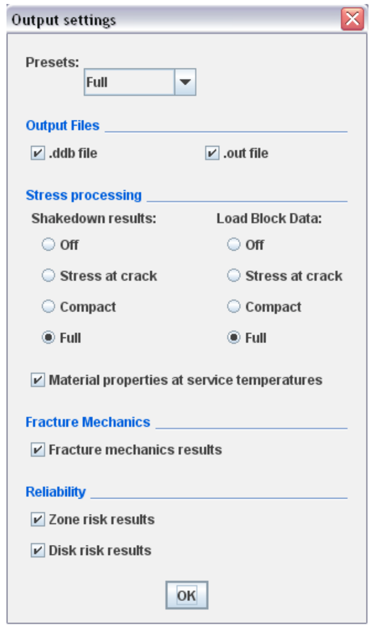


Figure 12: DARWIN output verbosity control settings

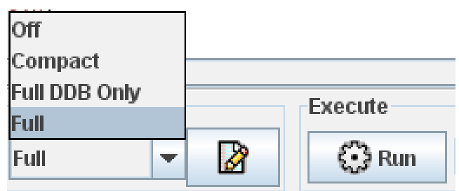


Figure 13: Predefined output modes for DARWIN output verbosity control

Stress Gradient Search Enhancement

The stress-processing module in DARWIN obtains the stress at each point along the crack growth path by interpolating the nodal stress values within the element that contains the point. A new point containment algorithm has been implemented to improve the robustness of the current point containment algorithm. It is executed when the previous algorithm fails to locate an element associated with a crack growth path point.