DARWIN® 7.1 Release Notes

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Southwest Research Institute®

Summary of New Capabilities

DARWIN 7.1 includes the following new features:

- Deterministic Analysis Mode
- FAA Hole Feature Surface Damage Analysis Mode
- Automatic Generation of Crack Growth Life Contours
- Treatment of Non-Normal Bivariant Corner Cracks
- HCF Threshold Check
- User-Supplied K Tables
- Thermo-Mechanical Fatigue (TMF) Crack Growth
- Stress Level Sensitivity Stress Ratio Model for NASGRO FCG Format
- Treatment of Material Processing-Related Residual Stresses
- Additional Deterministic Fracture Mechanics Output
- Risk Assessment of Multiple Types of Anomalies
- Compute Life for a Specified Probability of Fracture
- Specify Crack Location by FE Node ID
- Fleet Assessment Module
- Unit Conversion
- Bug Report Generator
- LAF Accuracy Improvement

Deterministic Analysis Mode

In previous versions of DARWIN, users were required to provide risk-related data even if they intended only to perform a deterministic analysis. In DARWIN 7.1, the GUI was reorganized to enable the user to select the analysis method at the beginning of the assessment definition process. When the Deterministic Analysis mode is selected, the directory tree automatically adjusts to display only the input menus required for deterministic analysis (Figure 1). The "life model" menu was redesigned to allow the user to specify a different initial crack size for each zone, and to select from several options for termination of crack propagation. The "perform analysis" menu was also reorganized to display a summary of the initial crack sizes and other analysis details specified for each zone.

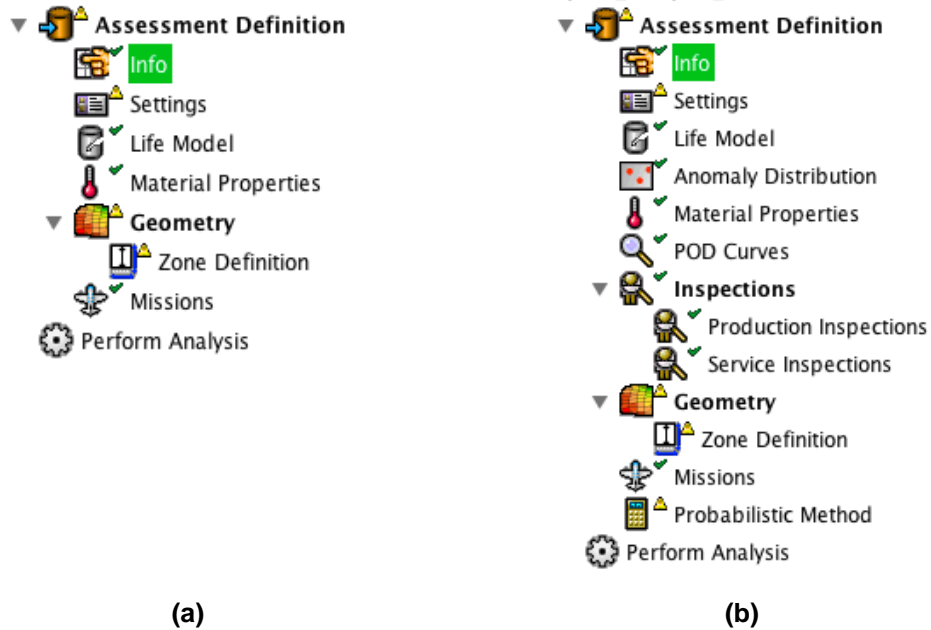**(a)**   **(b)**

Figure 1: The GUI was enhanced so that when the Deterministic Analysis mode is selected, the GUI directory tree automatically adjusts to display only the input menus required for deterministic analysis: (a) Deterministic Analysis mode, and (b) Risk Assessment mode.

FAA Hole Feature Surface Damage Analysis Mode

A new "FAA Certification" analysis mode was created to display the options that are available when using DARWIN for FAA certification analysis (Figure 2). When this analysis mode is selected, the GUI restricts the user to the anomaly types and analysis methods that are currently addressed by FAA Advisory Circulars. A new "Circular Hole Feature Surface Damage" anomaly type was added for FAA certification purposes that restricts the DARWIN surface damage capabilities to assessment of hole features. When the user selects this anomaly type, the following capabilities are disabled:

- Turned surfaces (use of 2D axisymmetric finite element models)
- Stress concentration factors (Kt)
- GUI capabilities for definition of blade slots
- Combined risk result output associated with multiple hole features (AC33.70-2 does not require combining risks from multiple hole features).
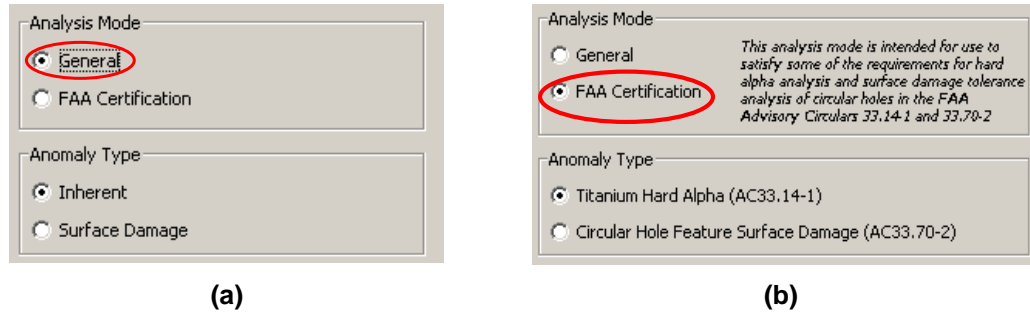
(a)   **(b)**

Figure 2: The GUI was restructured to display the options that are available when using DARWIN for FAA certification analysis: (a) General use options, and (b) FAA certification options.

Automatic Generation of Crack Growth Life Contours

A new capability was developed for automatic generation of life contours for application to 2D axisymmetric finite element models. When the user executes this option, an anomaly of one or more user-specified sizes is automatically placed at each of the nodes in the finite element model. The automatic geometry model process (autoplate) generates a fracture model at each anomaly location, and then the fatigue crack growth (FCG) lifetime to failure is computed for each model. The resulting family of calculated life results is displayed in the GUI using conventional contouring methods, as is often done for stresses. Example results are shown in Figure 3. The image on the left shows the stress contours, and the image on the right shows the corresponding FCG life contours. The life contours are shown as the logarithm (base 10) of the calculated life, since fatigue lives span a wide range and vary nonlinearly. This figure demonstrates that the stress hot spots (red regions of especially high stress) do not correspond exactly with the life hot spots (regions of especially low FCG life), due to the additional geometry factors that influence FCG life.
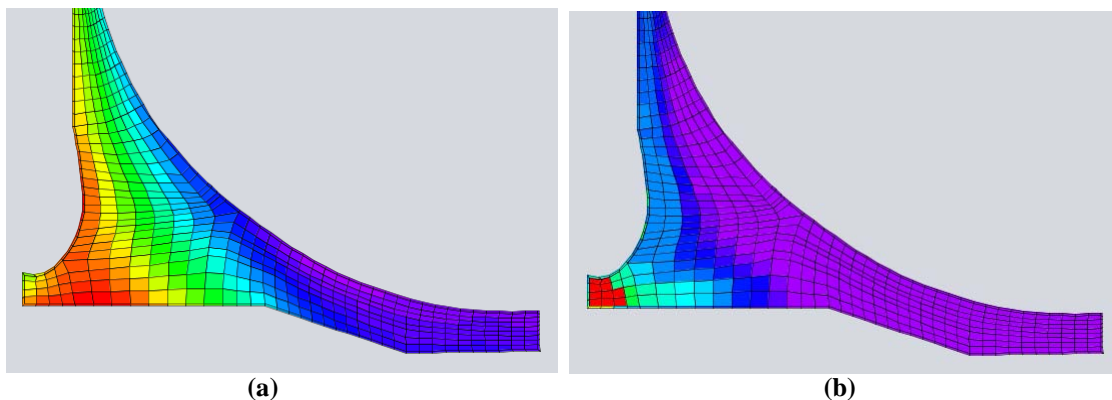

(a)   **(b)**

Figure 3:   **(a) Hoop stress contour plot for an axisymmetric impeller geometry, and (b) Corresponding DARWIN life contour plot.**

Treatment of Non-Normal Bivariant Corner Cracks

In previous versions of DARWIN, the bivariant corner crack solution (CC09) was limited to model geometries with 90° corners. In DARWIN 7.1, CC09 was enhanced to enable the user to define a crack and calculate a stress intensity factor (SIF) under general bivariant stressing at a corner whose included angle can vary ±5° from the customary 90°. These small variations commonly occur when creating 2D slices from 3D finite element models at corners that are nominally perpendicular. The corresponding GUI capability is illustrated in Figure 4.

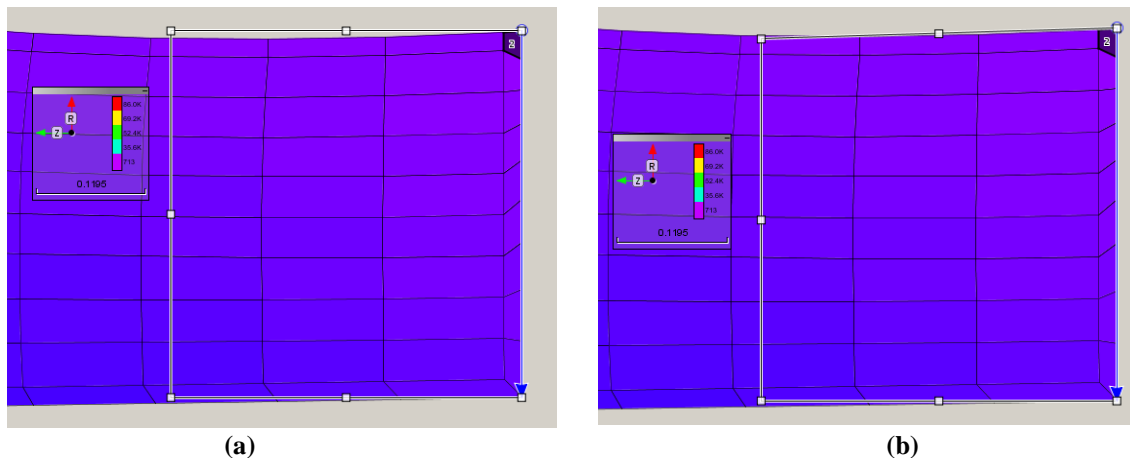| (a) | (b) |

Figure 4: Illustration of new GUI capability for bivariant corner cracks (CC09) at non-normal corners: (a) Placement of CC09 at a non-normal corner in the finite element model, and (b) Adjustment of CC09 corner angle to match the finite element geometry.

HCF Threshold Check

A new capability was implemented in DARWIN 7.1 that allows the user to include the influences of vibratory (HCF) stress values in fatigue crack growth and fracture risk computations. Fracture is assumed to occur when the stress intensity factor associated with the HCF stress exceeds the HCF fatigue crack growth threshold value provided by the user. The HCF threshold check is performed only once per mission in conjunction with the application of the peak LCF stress in the mission. The user provides either the range or the amplitude of the HCF stress corresponding to the peak LCF stress in the mission (Figure 5). Note that HCF stresses are not included in the calculation of damage from LCF cycles.
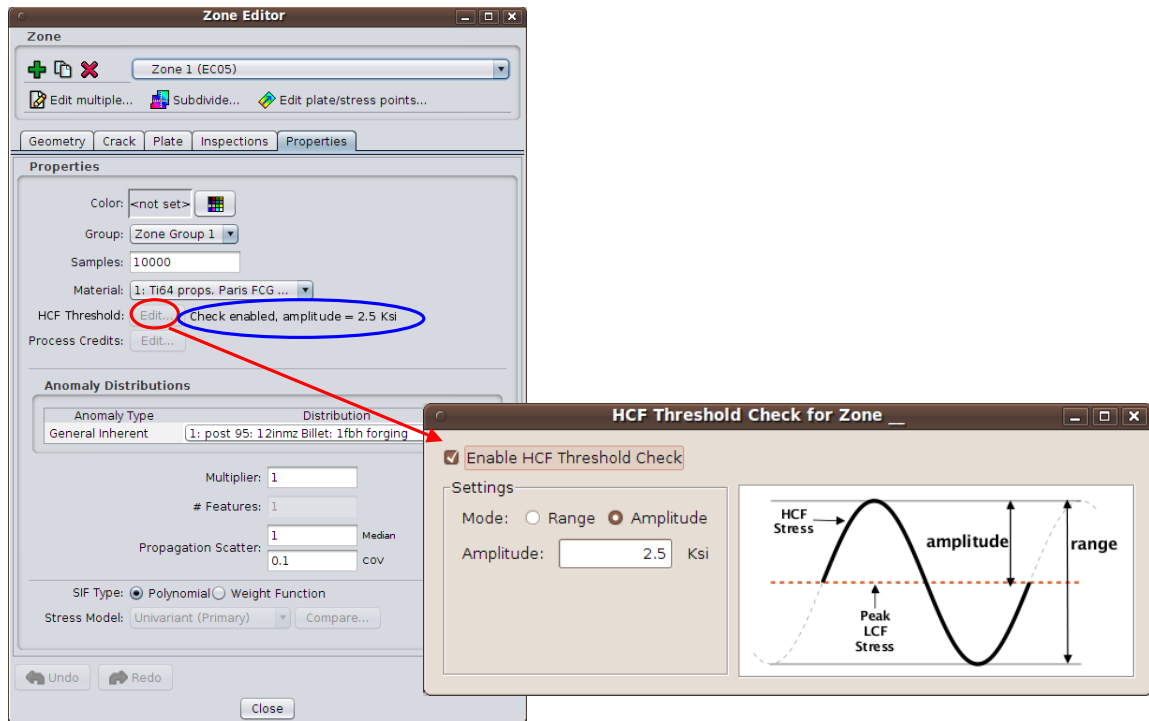
Figure 5: HCF threshold check capability.

User-Supplied K Tables

A new capability is included in DARWIN 7.1 that allows users to import stress intensity factor values (typically generated using 3D fracture mechanics software) into DARWIN for use in life and fracture risk computations. To use this feature, the user specifies the crack type as KA01 (user-defined K table) in the GUI zone editor (Figure 6), and provides a text file that includes tables consisting of stress intensity factors as a function of crack size (K vs. a) values for the zones that use this crack type. During execution, DARWIN reads the data directly from the file as needed. This capability is initially limited to a single mission, and will be enhanced to support multiple missions in the future.
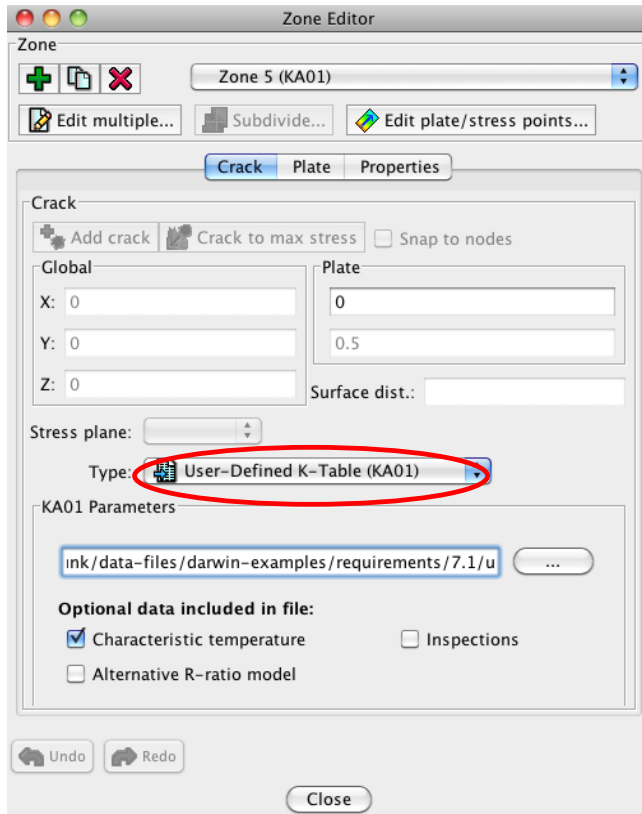
Figure 6: DARWIN 7.1 includes a new capability for user-supplied K tables.

Thermo-Mechanical Fatigue (TMF) Crack Growth

Several new algorithms were introduced in DARWIN 7.1 to provide support for thermo-mechanical fatigue (TMF) computations:

- Temperature Interpolation: The user can specify either of the following options for temperature interpolation of material properties: (1) temperature at the maximum stress value of each load pair, or (2) maximum temperature associated with either load step of the load pair.

- Damage Rainflow: This algorithm identifies the load pairing sequence based on the crack growth rates associated with each load step. In contrast with the existing stress rainflow algorithm in which the load pairing is based on stress magnitudes and is identical at all crack sizes, the load pairing sequence associated with damage rainflow may change as the crack propagates.

- Average da/dN: This algorithm computes average crack growth rates for each load pair based on an integration of crack growth rates as a function of temperature over the range of temperature values associated with the mission.

Stress Level Sensitivity Stress Ratio Model for NASGRO FCG Format

Stress level sensitivity (SLS) is an enhancement to the existing NASGRO FCG format that provides special treatment for zero or negative stress ratios. This is achieved by modifications to several of the NASGRO equation parameters (e.g., *f* function, threshold stress intensity factor range) within DARWIN.

Treatment of Material Processing-Related Residual Stresses

DARWIN was recently enhanced to provide treatment for residual stresses that may be introduced during material processing operations such as forging and heat treatment. DARWIN 7.1 includes a new capability to read full-field residual stress data that are provided by the user in the form of finite element model results files such as those generated by the DEFORM^{TM} software (Figure 7). During execution, the residual stress values along the crack path are extracted from the residual stress file and superimposed with the service stress values for application to life and risk assessment.
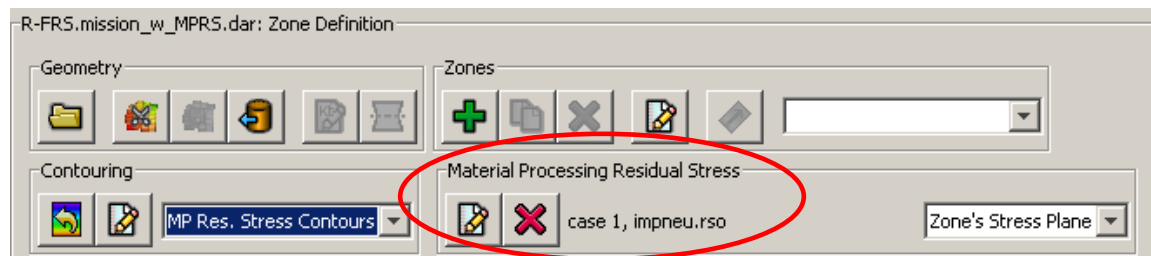

Figure 7. DARWIN was enhanced to allow the user to import residual stress files that are generated by the DEFORM software for use in life and risk computations.

Additional Deterministic Fracture Mechanics Output

In previous versions of DARWIN, the fracture mechanics-related output was limited to the values that were displayed in the GUI such as cycles to failure, crack size versus cycles, and maximum stress intensity factor versus cycles. This was sufficient for design purposes, but many users needed additional information when performing verification & validation studies. A new FCG results output file was introduced in DARWIN 7.1 that provides additional fracture mechanics-related output.   As shown in Figure 8, the GUI was enhanced to allow the user to specify the creation of this file prior to code execution. A complete list of the additional output is provided in the DARWIN User's Guide.
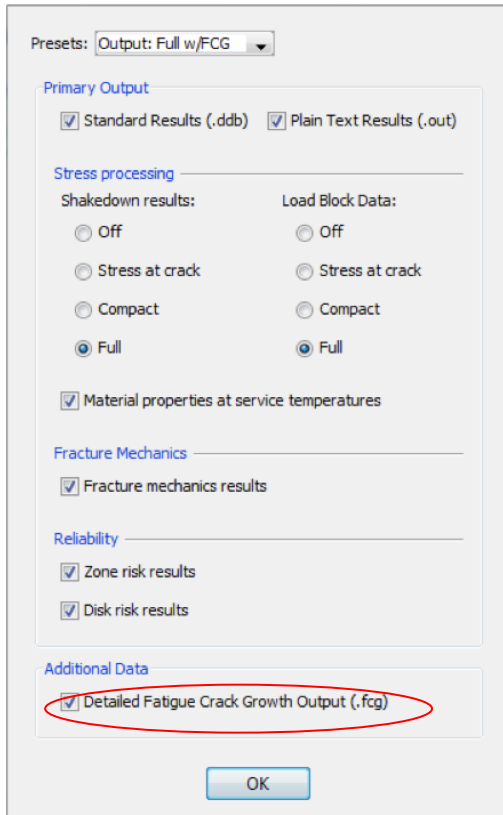
Figure 8: Enabling the detailed FCG results output file.

Risk Assessment of Multiple Types of Anomalies

Previous versions of DARWIN were limited to a single type of anomaly (e.g., hard alpha titanium, or surface damage) with a single distribution of anomalies in each zone. However, some materials may have several different types of anomalies present in a zone (e.g., both pores and inclusions), each with a different anomaly distribution, and this could not be addressed in previous versions of DARWIN. A new capability was developed that allows the user to create zones that have more than one type of anomaly and to view the influences of the various anomaly types on the risk of fracture for the zone and disk.

Compute Life for a Specified Probability of Fracture

In previous versions of DARWIN, the probability of fracture was reported for a user-specified number of flight cycles. If the user needed to know the number of flight cycles associated with the target risk, it could only be accomplished by adjusting the input by trial and error until the desired result was obtained. An algorithm was developed in DARWIN 7.1 (Figure 9) that predicts the number of flight cycles associated with a user-specified probability of fracture value (P_f or target risk).   For the FAA hole feature analysis mode, the algorithm will identify the life at which

the risk-limiting zone reaches the specified P_f. For all other analysis modes, it will identify the life at which the total disk risk reaches the specified P_f. Life values associated with the specified P_f are displayed in the GUI results section.
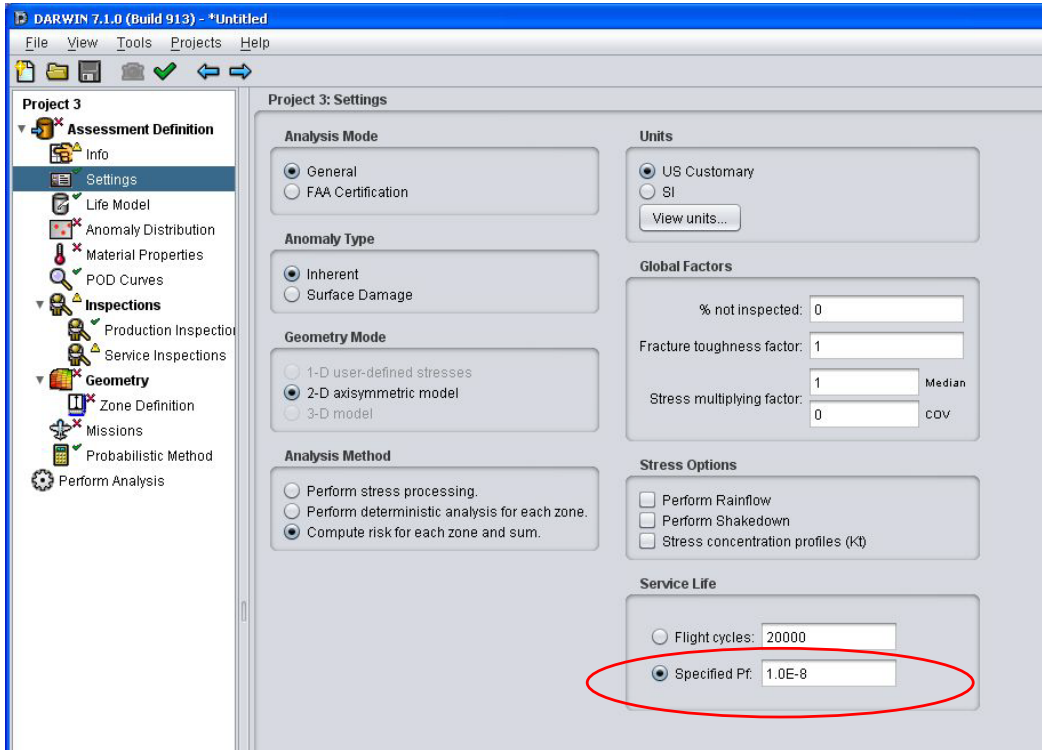

Figure 9: An algorithm was developed in DARWIN 7.1 that predicts the number of flight cycles associated with a user-specified probability of fracture (target risk) value.

Specify Crack Location by FE Node ID

When using 3D finite element models to describe component geometry, the user must define the location of the anomalies at nodes on the external surfaces of the FE model. In previous versions of DARWIN, the user specified the anomaly location by selecting nodes directly on the FE model. A new capability has been implemented that enables the user to specify the node ID directly.
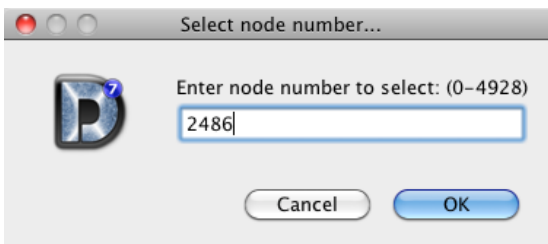

Figure 10: DARWIN was enhanced to enable the users to define the slice location in a finite element model by specifying the node ID.

Fleet Assessment Module

A new DARWIN capability was developed that enables the user to apply the results of multiple DARWIN component risk assessments to predict the fracture risk of engines associated with an aircraft fleet. This new capability was implemented as a separate module that is accessed via the DARWIN Tools menu, illustrated in Figure 11.
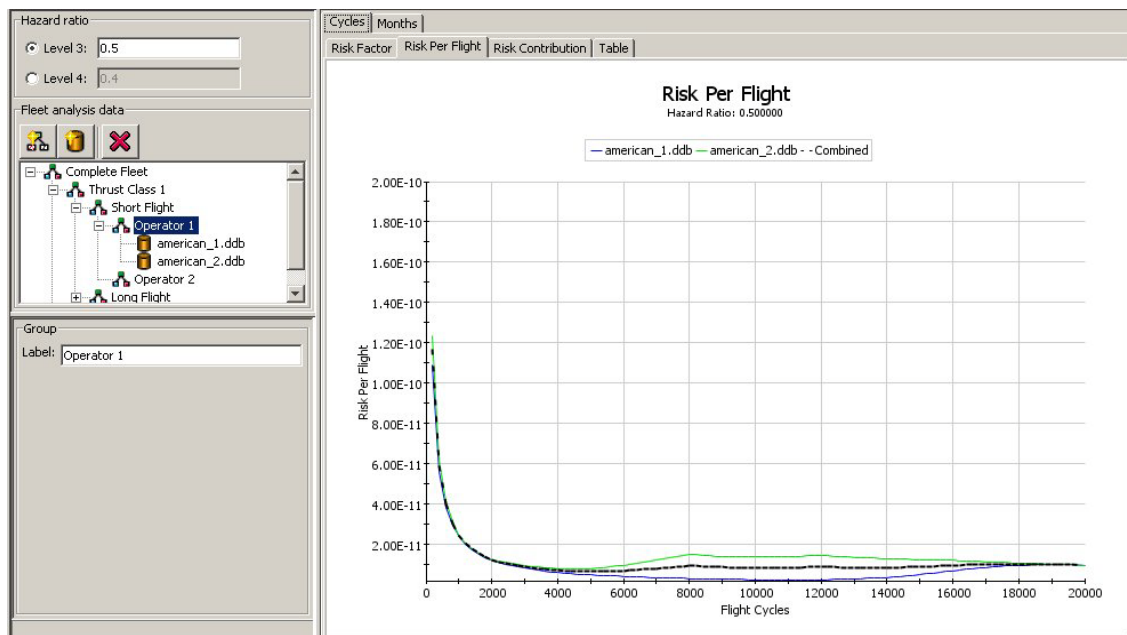

Figure 11: The DARWIN Fleet Assessment module can be used to assess the risk associated with an aircraft fleet based on risk results from multiple DARWIN results files.

Unit Conversion

In previous versions of DARWIN, the millimeter was used as the standard unit for rotor geometry dimensions in SI units. In DARWIN 7.1, *the standard unit for rotor geometry dimensions for the SI system of units has been changed from meters (m) to millimeters (mm)*. Also, the standard unit for stress values in DARWIN is Ksi, but many stress models are in psi units. To address these issues, a new unit conversion tool is now included in DARWIN (Figure 12). It facilitates the conversion of the rotor geometry dimensions in existing SI-based DARWIN analysis files to the new standard unit. It also converts stress values that are in psi units to the Ksi units that are used in DARWIN. The tool updates geometry (*.uif) and stress (*.uof) neutral files associated with the analysis file to include keywords indicating the units associated with these files. The conversion tool is automatically activated whenever the user loads a file into the DARWIN GUI that does not include the new keywords.

Note: The standard length unit for library files in SI units continues to be in meters (e.g., anomaly distribution, material properties).

Since DARWIN 7.1, the standard unit for geometric values has changed from meters (m) to milimeters (mm) for the SI system of units. Geometric values in the DARWIN analysis file and the associated geometry neutral file(s) (*.uif) will be converted in accordance with the new unit standard. Additionally, the associated geometry (*.uif) and stress (*.uof) neutral file(s) will be updated with newly required unit definition keywords.

Units

Analysis file: AC33.70-2.dat
System of units: SI

Please indicate the units used in the loaded analysis file.

Input: m, MPa, °C
○ US ◉ SI
Length: ○ mm ◉ m

Output: mm, MPa, °C
○ US ◉ SI

Convert

Figure 12: A new unit conversion tool is now included in DARWIN that facilitates the conversion of rotor geometry dimensions and stress values to the standard units that are used in DARWIN.

The DARWIN finite element model translator program FE2NEU was enhanced to provide unit conversion of geometry and stress values (Figure 13). It supports conversion of units for finite element model results (ANSYS *.rst files and ABAQUS *.odb files) as well as SIESTA neutral files (*.uif, *.uof). It can convert finite element results that use units other than the DARWIN standard units for geometry, stress, and temperature to the appropriate units. FE2NEU was also enhanced to allow the user to convert geometry and stress files from one system of units to another (e.g., from US units to SI units).
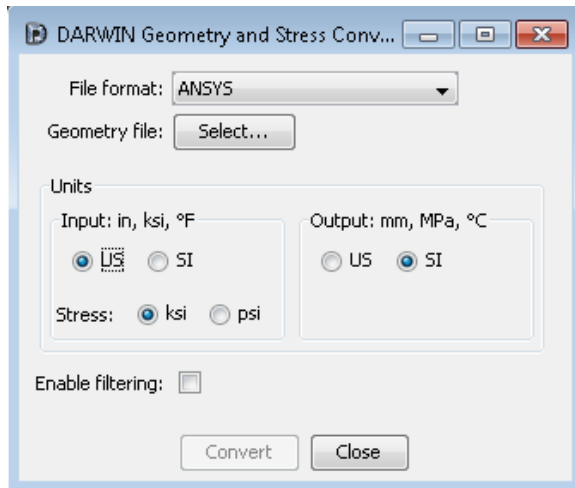
Figure 13: The DARWIN finite element model translator program FE2NEU was enhanced to provide unit conversion of geometry and stress values.

Bug Report Generator

A new file export tool has been developed to assist the user in providing data files associated with DARWIN bug reports. The new "export diagnostics" tool (available in the "tools" menu) allows the user to specify the file types to include in the bug report and combines them into a single compressed file that can be sent to Southwest Research Institute. A list of the available file types is provided in Figure 14.
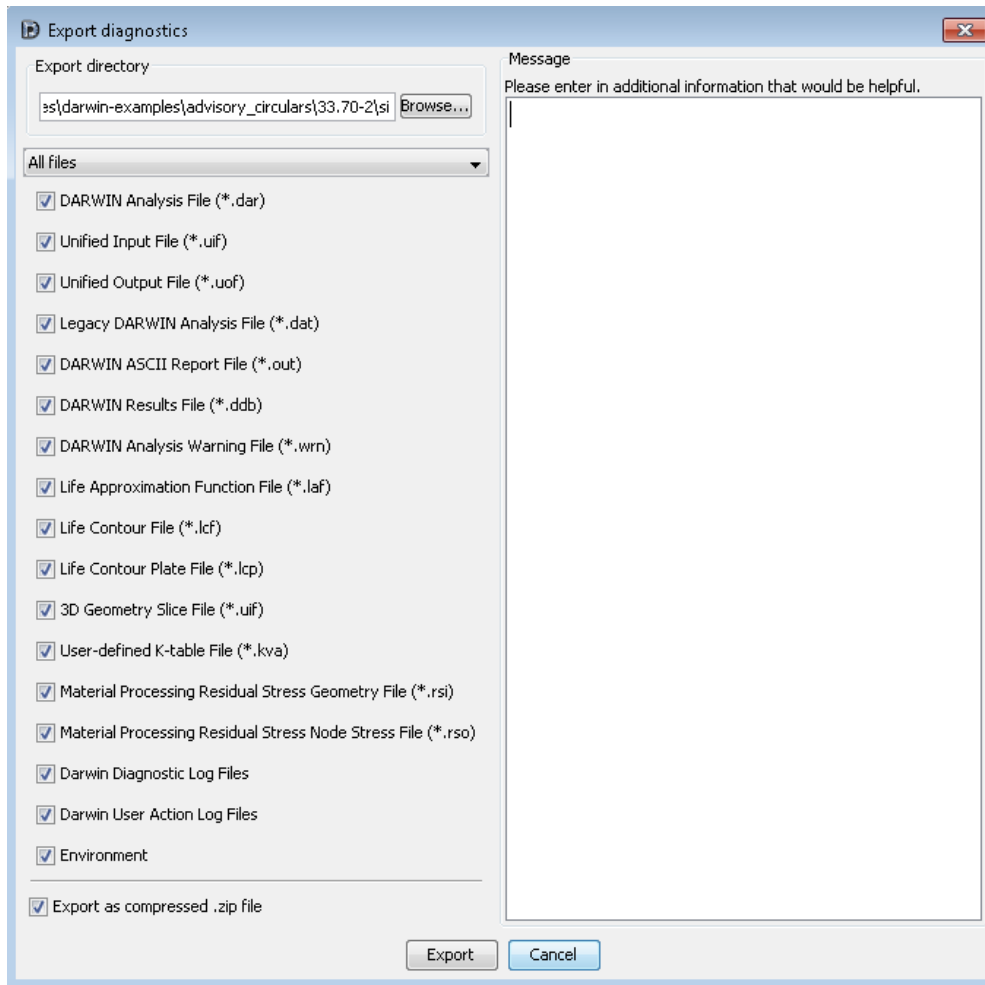
Figure 14: The bug report generator assists users by packaging user-selected files into a single compressed file that can be sent to Southwest Research Institute for diagnosis.

LAF Accuracy Improvement

The Life Approximation Function (LAF) is a method that generates a response surface of crack area and life values (LAF table) that is used as a surrogate model for reliability computations. In previous DARWIN versions, the crack areas in the LAF table were computed at fixed intervals by interpolating values at the nearest cycles provided by the Flight_life crack growth module. LAF was recently improved by adjusting the LAF table intervals to match the reporting intervals of Flight_Life. This not only improved the accuracy of the LAF method, but also slightly improved efficiency by eliminating one of the interpolation steps that was previously required to construct the LAF table. Verification test results indicate that the LAF accuracy improvement may result in minor changes in probability of fracture results for disk assessments that use the LAF method.