

# DARWIN<sup>®</sup> 8.2 Production Release Notes

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Southwest Research Institute<sup>®</sup>

## Summary of New Capabilities

DARWIN 8.2 includes the following new features:

- 3D Inherent Analysis
- Shop Visit Anomalies
- Mission Mixing
- FRANC3D Crack type
- Chamfered Corners
- Material Scaling Module
- Random Average Grain Size
- Random Anomaly Orientation
- Corrective Actions
- GP Importance Sampling
- High-Cycle Fatigue (HCF) Stresses from FEM
- 3D FEM Residual Stress
- GUI Settings Menu Modifications
- Material Properties File Link

## 3D Inherent Analysis

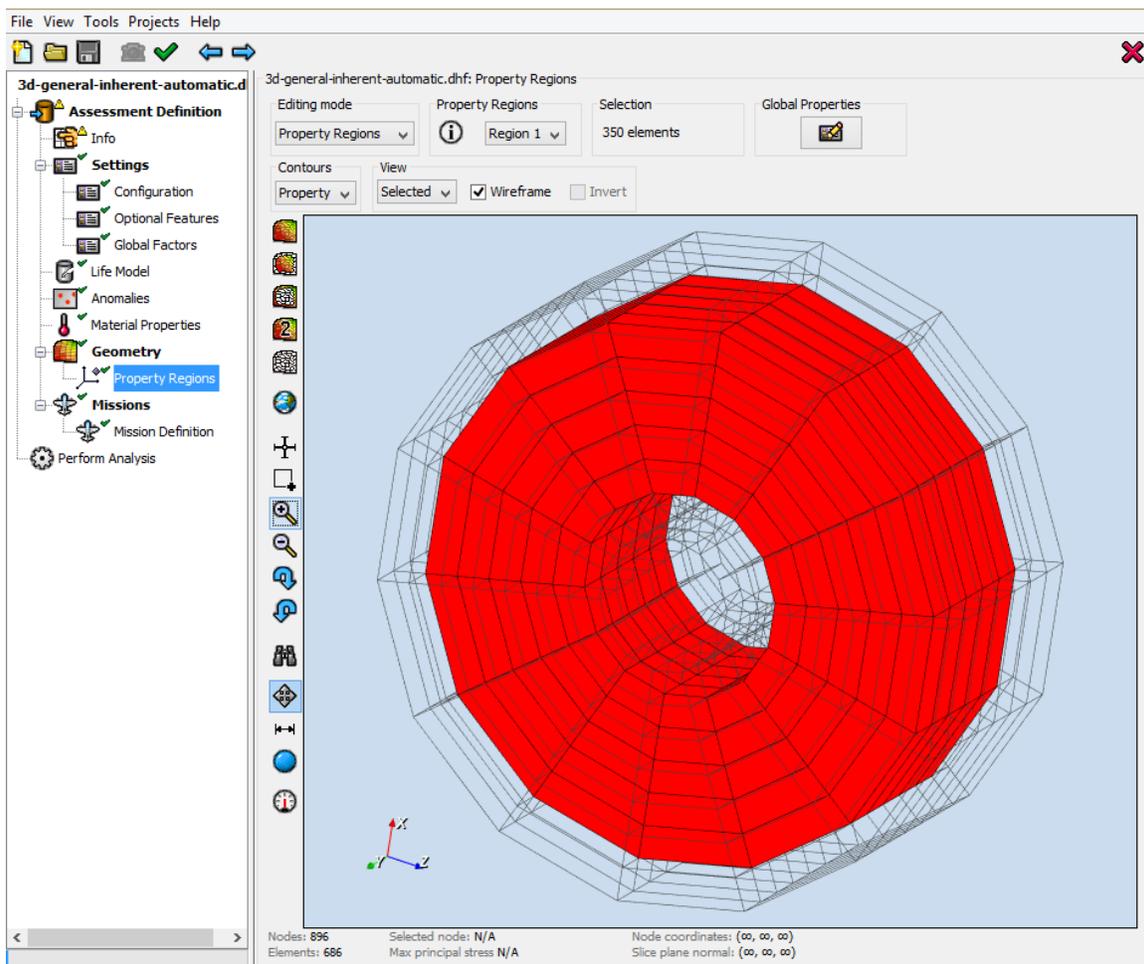
Increased computational resources enable more complex and higher fidelity models of aerospace and power generation components. Compromises once made to reduce computational demands, such as 2D axisymmetric models where the cross section remains constant around an axis, are no longer necessary in the design process of turbine rotors. Analysis of inherent anomalies (e.g., hard-alpha particles) in earlier versions of DARWIN has been limited to 2D axisymmetric geometries. 3D geometries were only available for the analysis of surface damage.

New capabilities in DARWIN 8.2 support 3D analysis of life predictions and fracture risk assessments for general inherent anomalies. DARWIN 8.2 now enables 3D geometries imported from 3D finite element (FE) models to be analyzed with internal inherent anomalies in addition to the existing 3D surface damage analysis.

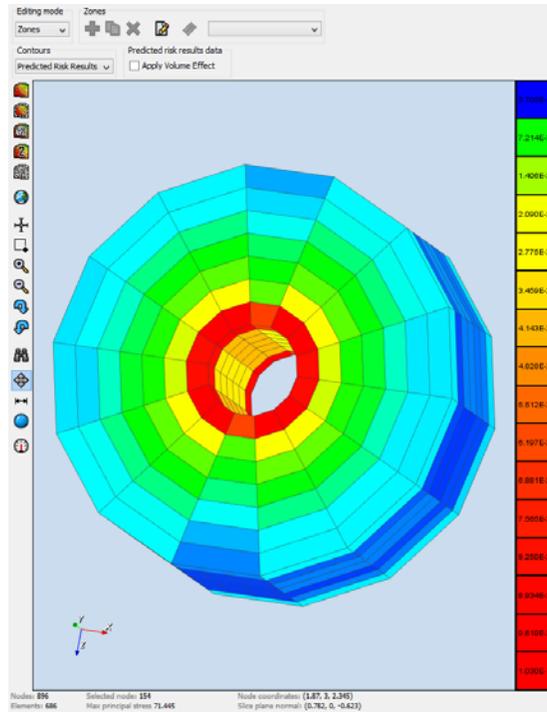
DARWIN 8.2 supports inherent anomalies in 3D geometries within the exhaustive autozoning and optimal autozoning frameworks. Graphical-user interface (GUI) enhancements now enable user definition of property region information (*i.e.*, material response, anomaly distributions, inspection schedules, and mission regions) directly on the 3D FE model. Properties may be defined for the entire model, surface and/or internal elements only (Fig. 1), or element-by-element. DARWIN employs this information to determine the 3D zones in the model based on using either exhaustive

autozoning (one zone for each element) or optimal autozoning (zones are automatically sized to minimize risk based on user-defined restrictions, *e.g.*, the probability of fracture).

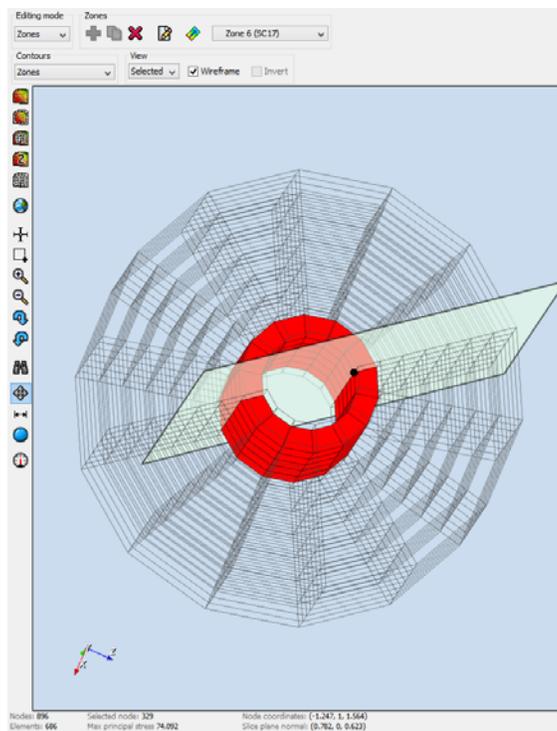
Similar to 2D autozoning, 3D autozoning results include stress, life, and risk information. Zone-level information enables users to visualize 3D contours of the stress variations, life predictions, and risk assessments (Fig. 2). Additional information, such as crack tip location, plate definition, and the slice geometry (now stored within the analysis file), can be visualized zone-by-zone using improved visualization tools (Fig. 3). DARWIN 8.2 also supports user re-definition of these features following an autozoning analysis. For example, the crack tip can be translated to different locations within a zone. DARWIN 8.2 enables reanalysis of the modified input model.



**Figure 1:** In DARWIN 8.2, the graphical user interface (GUI) has been enhanced to provide additional visualization capabilities for 3D finite element (FE) models. Here, the user views only interior elements while defining a property region. Surface elements are shown with a wireframe mesh that can be hidden by the user.



**Figure 2: DARWIN 8.2 provides risk contours for 3D FE models with inherent anomalies.**



**Figure 3: In DARWIN 8.2, users have the option to view only the 3D elements belonging to a single zone as well as the crack location and slice plate for that zone.**

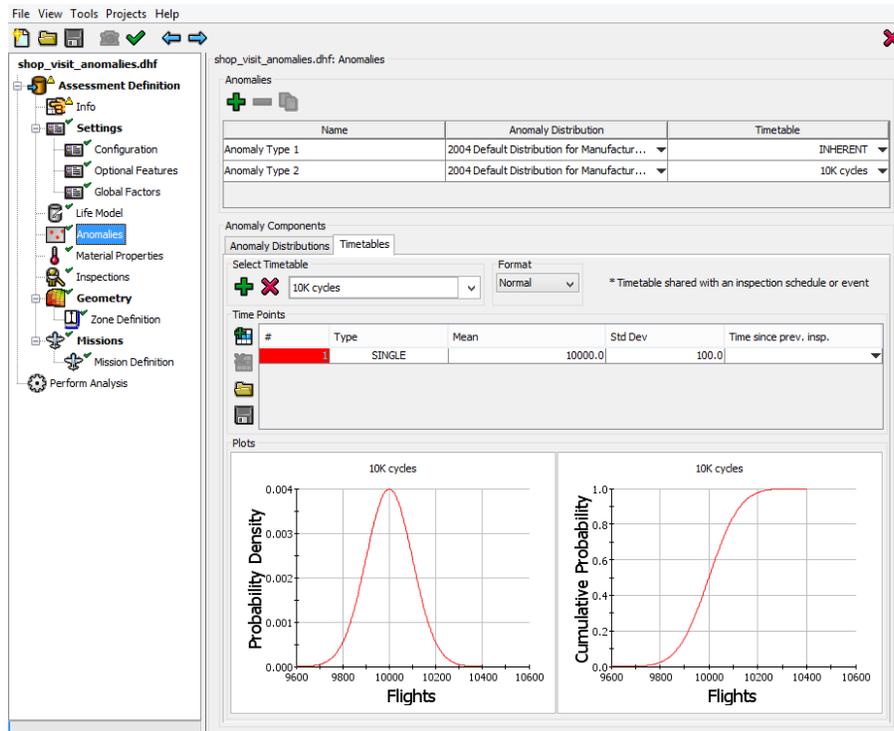
## Shop Visit Anomalies

Anomalies may sometimes be introduced on the surfaces of a component that is handled or inspected during routine maintenance. For example, an anomaly might not exist until cycle 5000 when it is introduced during an inspection. Introducing these anomalies at the beginning of the service life may result in an overestimate of the risk of fracture.

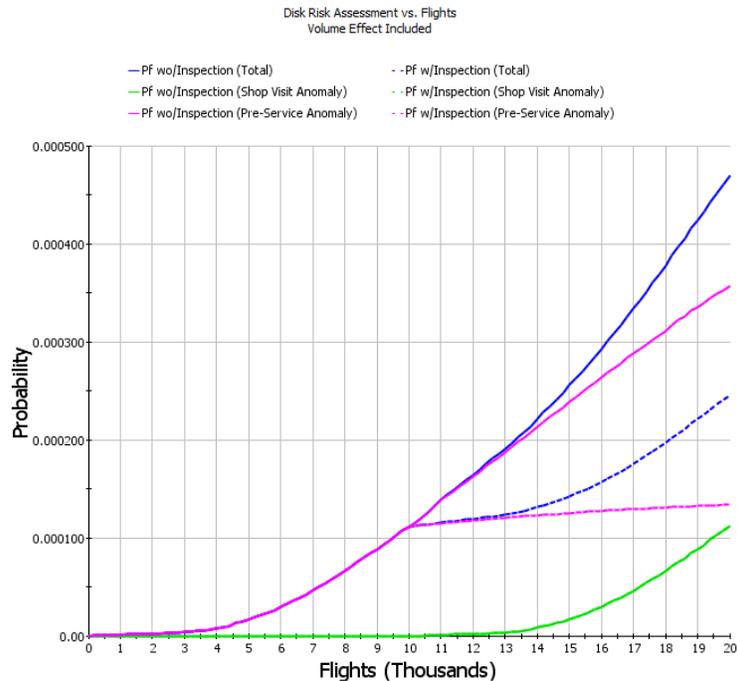
Previous versions of DARWIN have been limited to anomalies that are present before the part has entered service. In DARWIN 8.2, users have the option to define shop visit anomalies for improved risk assessments (Fig. 4). This feature is available for surface damage investigations of 1D, 2D, and 3D geometries. A new GUI menu (Fig. 5) has been introduced that enables the user to specify the size distribution and timetables associated with shop visit anomalies. The timetable may be linked to the timetable of inspection schedules if desired. DARWIN tracks risk associated with shop visit anomalies and quantifies its influence on the overall probability of fracture as shown in Fig. 6.



**Figure 4: DARWIN 8.2 includes a new capability for shop visit anomalies that is enabled via the optional features menu.**



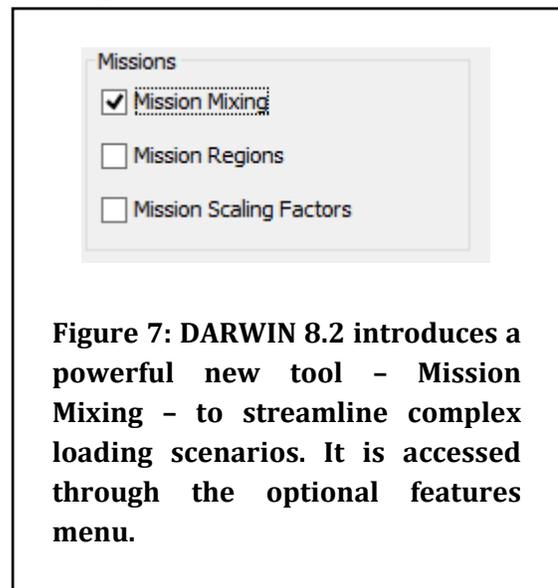
**Figure 5: A new GUI menu was introduced in DARWIN 8.2 that enables users to define distributions and timetables associated with shop visit anomalies. The timetable can be linked to inspection events.**



**Figure 6: DARWIN 8.2 displays the probability of fracture with and without shop visit anomalies. In this example, the inspection protocol reduces the overall risk of fracture but also introduces anomalies during the shop visit that increase risk.**

## Mission Mixing

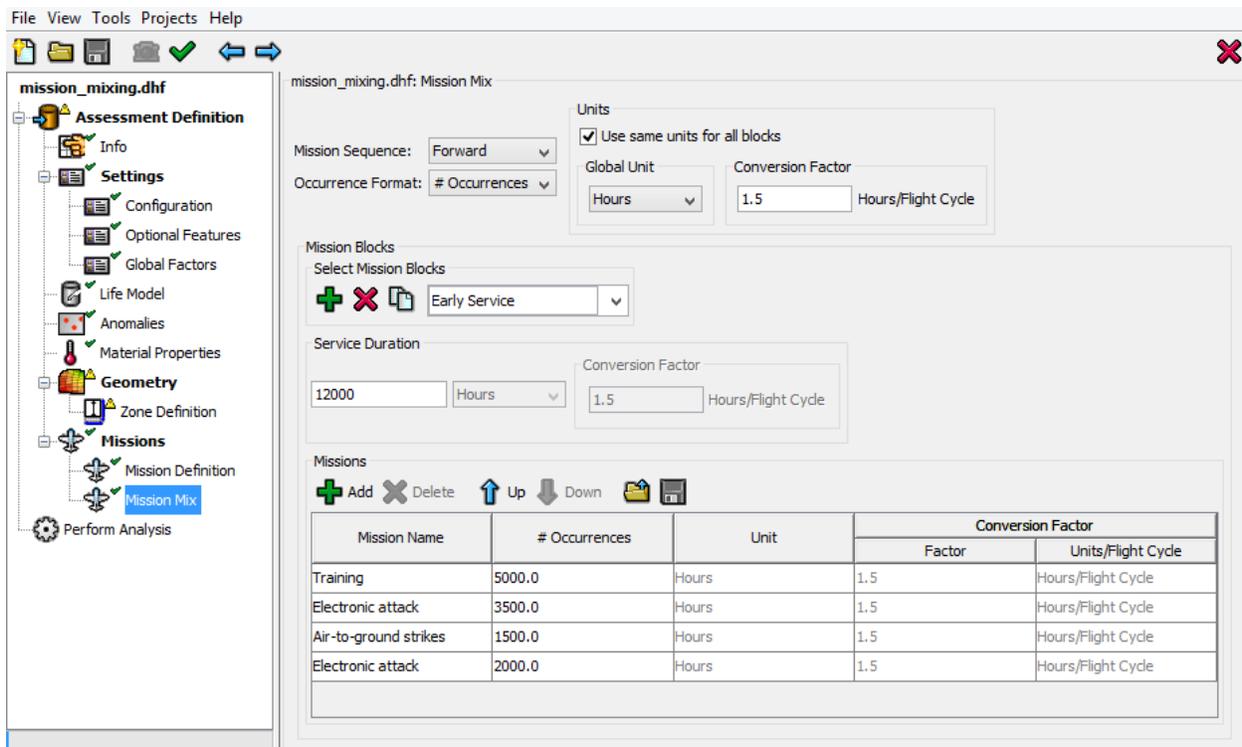
Flight profiles in aerospace components are often described in terms of missions that consist of individual load steps. A simple mission could consist of a single large load step to simulate ascent, several smaller steps for maneuvers, and another load step for descent. Previous versions of DARWIN supported the definition of missions and their combinations using mission mix scenarios. DARWIN 8.2 enhances this optional feature with several new capabilities and renames it “Mission Mixing” (Fig. 7). Users continue to define missions based on the load steps imported into DARWIN from FE analysis. Users satisfied with a single mission do not need to perform any additional tasks. However, other users will find the new mission mixing capability useful for complex loading profiles. Missions represent the first level grouping of load steps and can be grouped further into mission blocks. Mission blocks occur over some loading duration to define the entire flight profile.



**Figure 7: DARWIN 8.2 introduces a powerful new tool – Mission Mixing – to streamline complex loading scenarios. It is accessed through the optional features menu.**

Several options are available through the mission mixer (Fig. 8) to define the sequence of missions within a mission block. Duration times for missions and mission blocks may be described in terms of flight cycles, hours, and/or TACs. Separate mission blocks may have separate units, and DARWIN handles the conversion automatically. This mission sequence can be defined deterministically based on a forward and reverse progression of missions. Alternatively, users can define a random mission sequence set using a mission seed. Users provide either the number of times that a mission repeats or set a mission mix percentage for the mission block.

For example, consider an analysis with two missions A and B. Users could define a forward mission block where mission A occurs 1000 times followed by mission B occurring 9000 times. By changing the mission sequence from forward to reverse, the mission block would be mission B occurring 9000 times followed by mission A occurring 1000 times. Alternatively, a random mission sequence with a mission mix percentage for mission A and mission B of 10% and 90% respectively might lead to a mission B occurring for 2000 times, followed by mission A occurring 1000 times, followed by mission B occurring 7000 times. These scenarios demonstrate the increasing complexity offered by the advanced mission mixer available in DARWIN 8.2.



**Figure 8: DARWIN 8.2 has organized and simplified the description of complex mission scenarios through an enhanced mission mixing tool.**

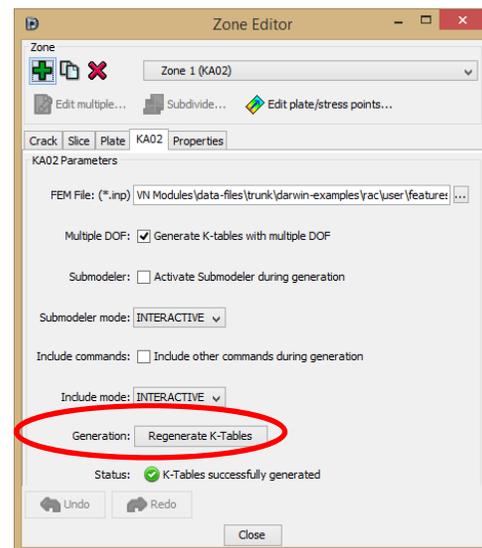
## FRANC3D Crack Type

DARWIN 8.2 enables users to generate tables of stress-intensity factor solutions for arbitrary, non-planar 3D geometries directly using a FE package — FRANC3D developed by Fracture Analysis Consultants. Previously, DARWIN has been limited to weight function solutions applicable to limited planar geometric configurations or limited to imported tables of stress-intensity factors described only by a single degree of freedom. The latest release of DARWIN automates the development of stress-intensity factor solutions through the new crack type KA02 available for 3D configurations with surface damage. DARWIN, FRANC3D, and either Abaqus or ANSYS communicate to develop the solution space (FRANC3D, Abaqus, and ANSYS are sold separately.) This computational framework significantly increases execution times and leads to solutions with comparable accuracy for cracks already covered by DARWIN. KA02 (Fig. 9) enables previously unavailable solutions for cracked bodies with complex (non-rectangular) shapes and for crack front shapes that are non-elliptical and/or non-planar.

After users select KA02, a new tab appears in the zone editor. Through this interface, users initiate a FRANC3D analysis that generates stress-intensity factor solutions as a function of crack growth by explicitly modeling the crack front in FE models. Various options (Fig. 10) are available for advanced users to control mesh generation and to improve solution quality. Tables of stress-intensity factors from FRANC3D are loaded into DARWIN automatically, and DARWIN interpolates among these known values to



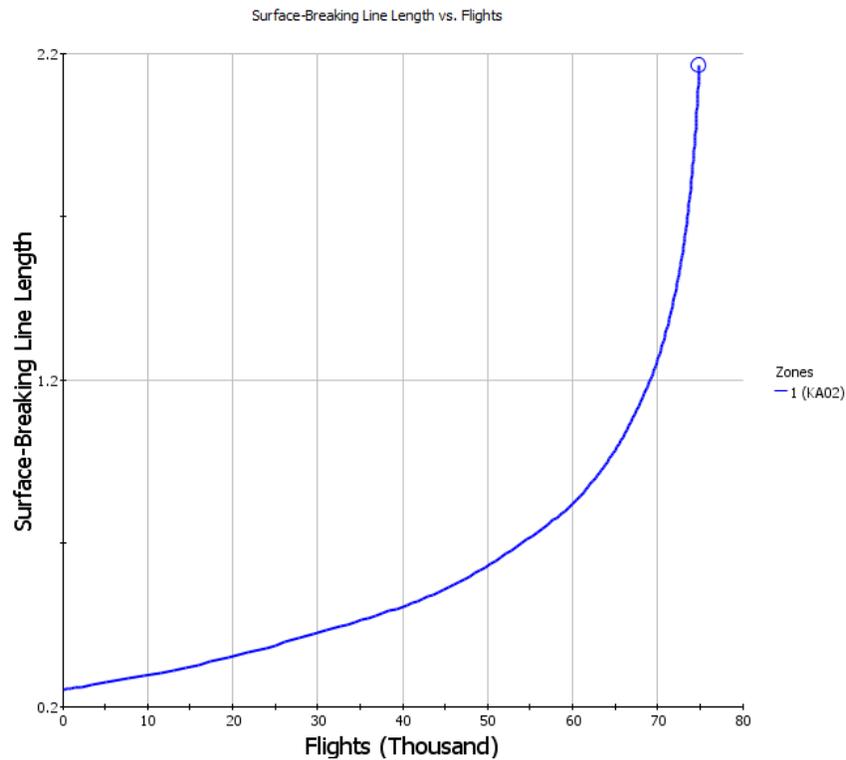
**Figure 9: Users can now select KA02, a crack type where tables of stress-intensity factors are generated using the FE software FRANC3D.**



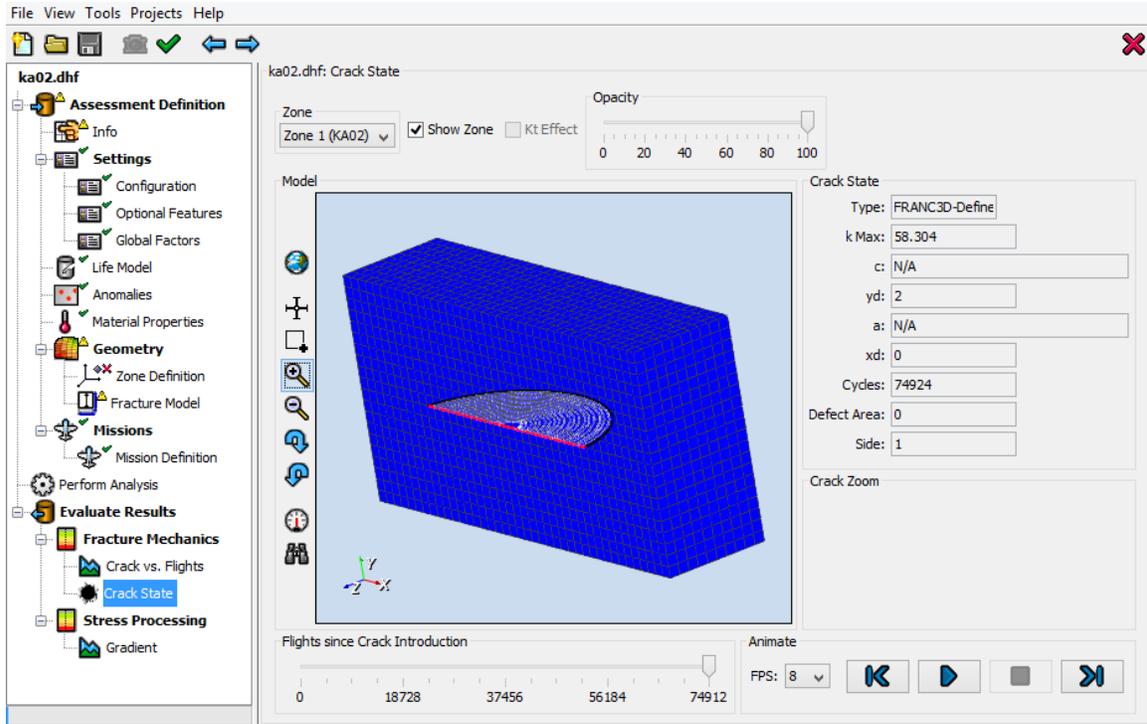
**Figure 10: Users generate tables of stress-intensity factors through the zone editor. Pressing the “Generation” button computes, processes, and imports crack-growth tables from FRANC3D based on user selected options.**

estimate life.

DARWIN provides improved visualization capabilities to interrogate results. For example, users can view the surface-breaking line length (the intersection of a crack with the component's outer surface) as a function of loading history (Fig. 11). Enhanced visualization capabilities in DARWIN 8.2 enable users to illustrate crack growth within the 3D FE model (Fig. 12). Users can rotate the model, change its opacity, and zoom into areas of interest, such as the region where the crack tip interacts with the near surface of the component.



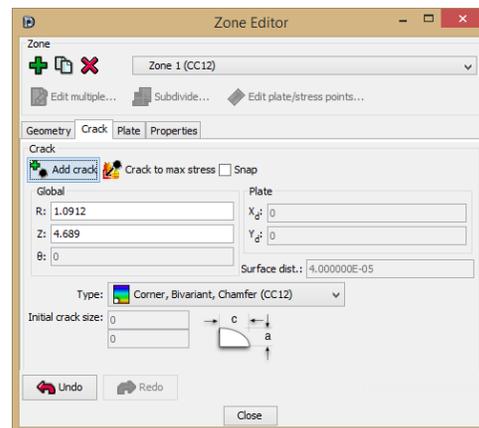
**Figure 11: DARWIN 8.2 tracks the surface-breaking length line vs. flights for the KA02 crack type that interfaces with FRANC3D.**



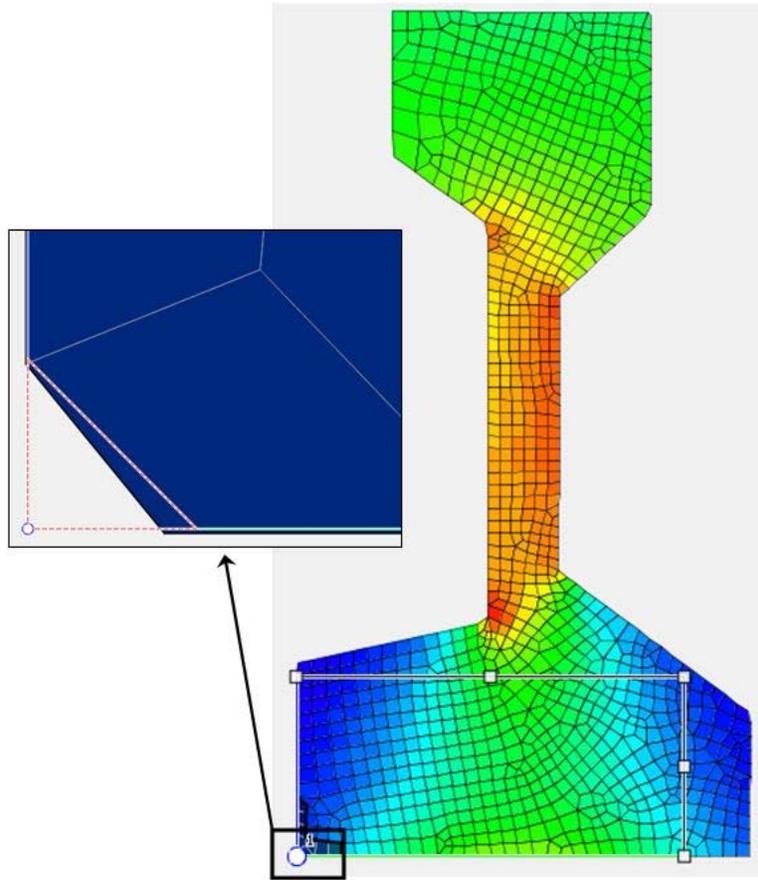
**Figure 12: Users can animate crack growth results through the graphical interface and visualize crack growth in the 3D geometry when using KA02.**

## Chamfered Corners

DARWIN 8.2 features a new stress intensity factor solution (CC12) for a quarter-elliptical surface crack at a chamfered corner. This bivariate solution is optimal for crack locations where the stress gradient varies significantly in more than one direction. The CC12 solution is accessed via the zone editor (Fig. 13) for 2D geometries. Cracks modeled by CC12 extend over the entire chamfered region and are enabled for zones that are defined manually. Users provide the chamfer dimensions, place the crack, and define the plate. As shown in Fig. 14, the plate definition tool displays the assumed chamfer geometry to facilitate the placement of the crack on the chamfered location.



**Figure 13: DARWIN 8.2 features a new crack type for corner cracks on chamfered corners.**



**Figure 14: DARWIN 8.2 supports definitions of corner cracks at chamfered corners using enhanced visualization tools to place cracks, locate plates, and track chamfered corners.**

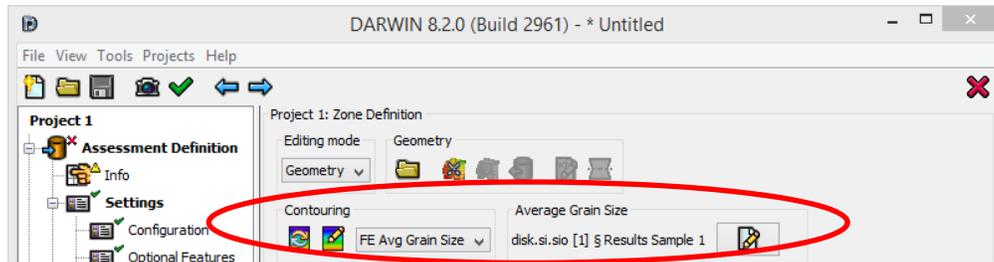
## **Material Scaling Module**

Material microstructure and material properties can vary throughout a component comprising the same nominal material composition. These variations can arise from local differences in the thermal-mechanical history of the material during the manufacturing process, including forging, heat treating, and machining (among others). Manufacturing-driven local variations in properties can provide unique opportunities to optimize component integrity or reliability, if they are properly understood and managed. New computational tools such as DEFORM™ are emerging to predict location-specific variations in microstructure. It may be possible to adjust the manufacturing process in order to tailor the microstructure in each region of a component to provide optimum material properties for damage tolerance.

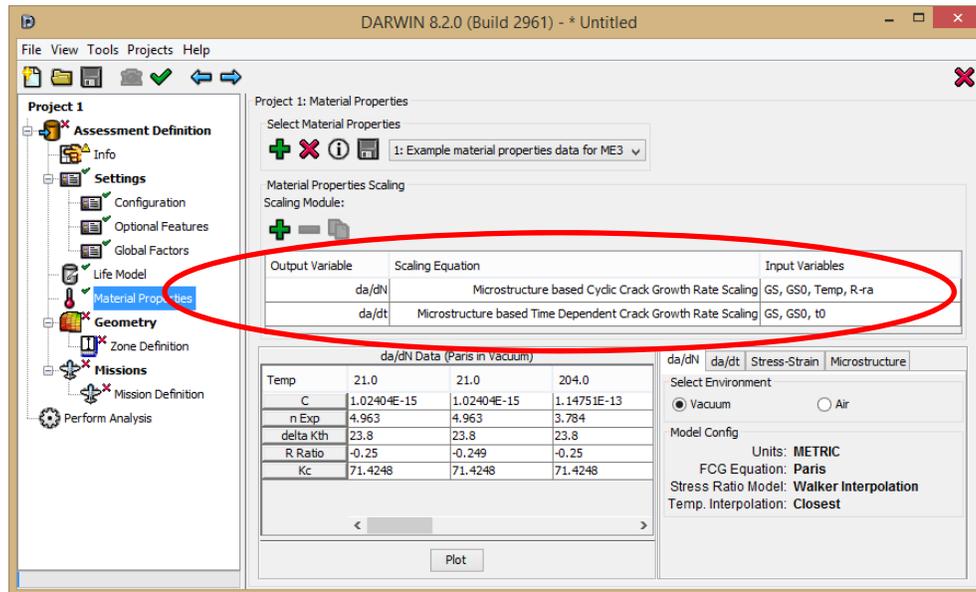
A new material properties scaling capability is provided in DARWIN 8.2 that adjusts material properties based on location-specific microstructure information from DEFORM. It includes a material scaling module that computes scaling factors based on location-specific and reference microstructure data. The new module has been implemented as a shared object (similar to the

existing DARWIN formation module). This format enables users to have direct access to the module with the option to provide their own scaling equations. The scaling factors are then applied to material properties that are provided by the user via the existing material properties file.

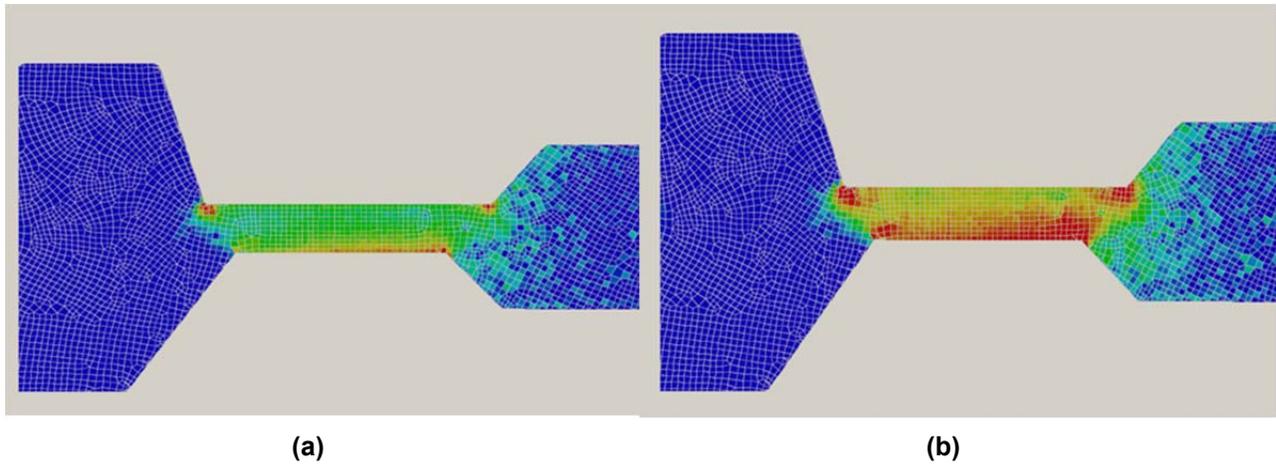
The material properties scaling capability currently supports scaling of cyclic and time-dependent fatigue crack growth rates based on deterministic or random average grain size information from manufacturing process simulation software such as DEFORM (Figs. 15 & 16). This enables users to assess the influence of grain size on fatigue crack growth life and fracture risk (Fig. 17).



**Figure 15: The new material properties scaling capability in DARWIN 8.2 enables users to import and visualize average grain size information from manufacturing process simulation software such as DEFORM.**



**Figure 16: The new material properties scaling capability enables scaling of cyclic and/or time-dependent material properties based on internal or user-provided scaling equations.**



**Figure 17: The new material properties scaling capability enables users to assess fracture risk both without (a) and with (b) the effects of grain size scaling.**

## Random Average Grain Size

Manufacturing process simulation (MPS) software (*e.g.*, DEFORM) can provide supporting data for modeling random distributions of grain sizes to enable user assessments of its influence on fatigue crack growth life and fracture risk. This information is supported through the material properties scaling capability introduced in DARWIN 8.2. New capabilities have been introduced to define, process, and visualize results associated with modeling random average grain sizes. The user provides average grain size files containing one or more sets of average grain size results from MPS software. Each result set or “data sample” is based on a unique combination of manufacturing process variables.

DARWIN enables users to select multiple average grain size files and to define the random parameters associated with the manufacturing process input variables (Fig. 18). The user can view grain size contours associated with each average grain size result set (Fig. 19).

During probabilistic life assessments, an average grain size response surface is created based on the user-provided average grain size results files. Random values associated with the manufacturing process variables are propagated through the response surface to obtain random average grain sizes at each FE node. DARWIN provides 2D contour plots of the computed random average grain sizes and scaling factors (Figs. 20 and 21, respectively) for cyclic and time-dependent fatigue crack growth rates at selected probability distribution percentile values.

Average Grain Size Data

Data Samples

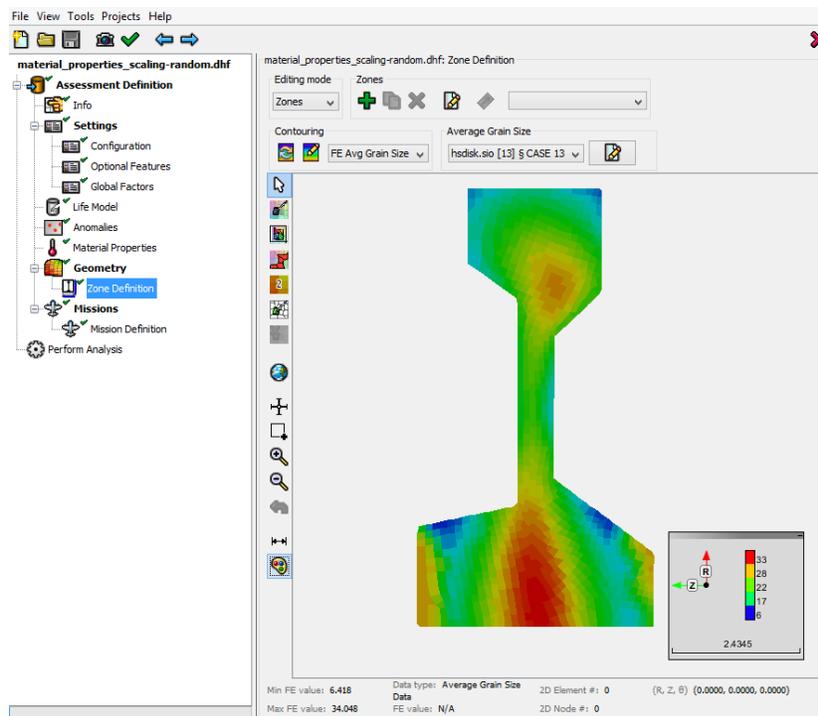
Response Case	Nominal?	FLOW...	FRICT...	FRICT...	FRICT...	FRICT...	GRAL...	OBJECT...	PROC...	PROCESS...	SPEED_1	SPEED_2	STOPPING...
hdisk.sio [12]	no	0.38934	0.369443	0.397991	0.316245	0.334034	30.2607	1801.38	17.7556	16.0677	1.11861	1.02866	4.22456
hdisk.sio [13] § CASE 13	yes	0.50788	0.275253	0.232296	0.321736	0.300701	28.7009	1793.77	24.0841	11.4483	1.13433	1.27744	4.07258
hdisk.sio [14]	no	0.455497	0.376309	0.20484	0.231096	0.2471	27.1508	1793.25	15.5826	8.76417	1.43288	1.19957	4.23569
hdisk.sio [15]	no	0.725052	0.269203	0.313057	0.293965	0.326948	26.7358	1779.54	21.7696	13.9862	1.29452	0.931893	4.10314
hdisk.sio [16]	no	0.957044	0.379449	0.305446	0.247489	0.231061	21.0821	1813.5	18.1755	13.4883	1.04245	1.41875	4.12071

Input Variable Definitions

Name	Distribution	Description
GRAIN_SIZE	Lognormal: $\lambda=3.3476$ , $\zeta=0.19838$	Grain Size
OBJECT_TEMP	Normal: $\mu=1800$ , $\sigma=14.523$	Object Temp
PROCESS_DURAT...	Lognormal: $\lambda=2.8322$ , $\zeta=0.24513$	Process Duration 1
PROCESS_DURAT...	Lognormal: $\lambda=2.5651$ , $\zeta=0.27431$	Process Duration 2
SPEED_1	Lognormal: $\lambda=-0.040375$ , $\zeta=0.28417$	Speed 1

Close

**Figure 18:** The new material properties scaling capability enables users to select multiple average grain size results files and to define the random parameters associated with the manufacturing process input variables.



**Figure 19:** DARWIN 8.2 enables users to view average grain size contours associated with multiple FE grain size results from manufacturing process simulation software such as DEFORM.

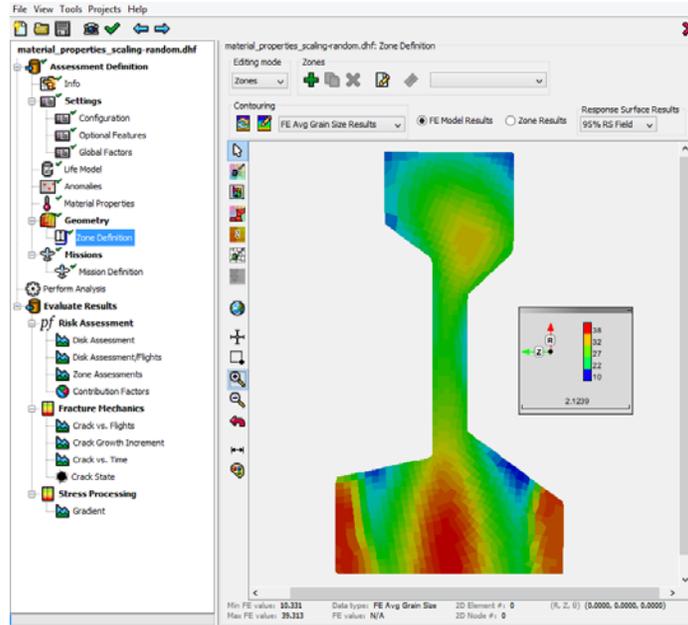


Figure 20: DARWIN 8.2 provides 2D contour plots of computed random average grain sizes at selected probability distribution percentile values.

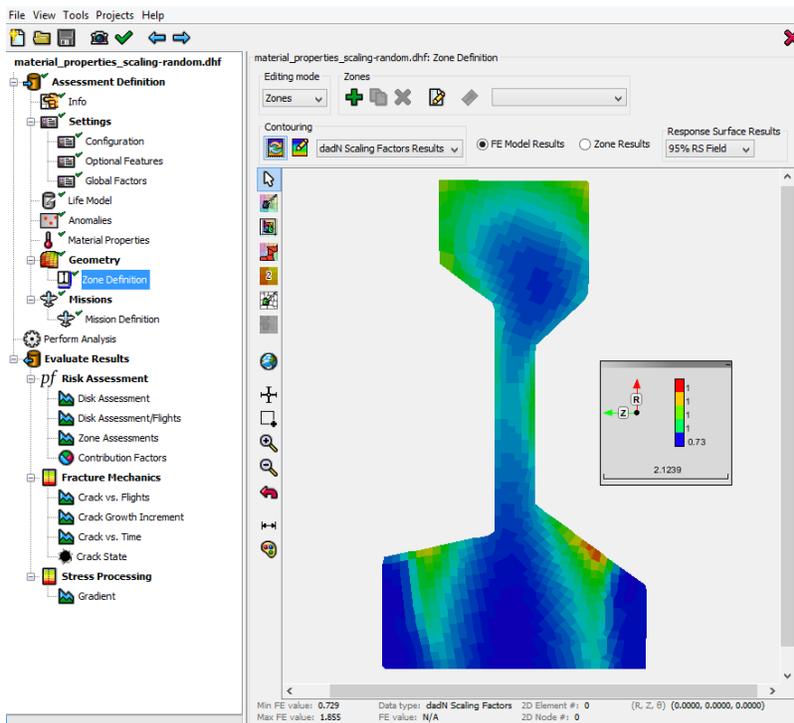


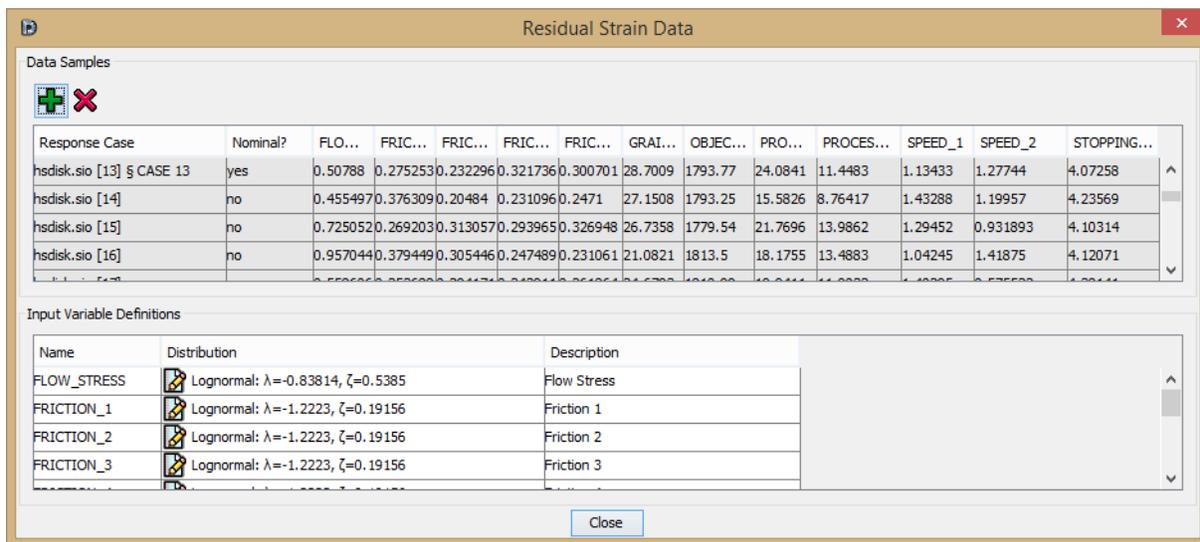
Figure 21: DARWIN 8.2 provides 2D contour plots of computed random scaling factors of fatigue crack growth rates at selected probability distribution percentile values.

## Random Anomaly Orientation

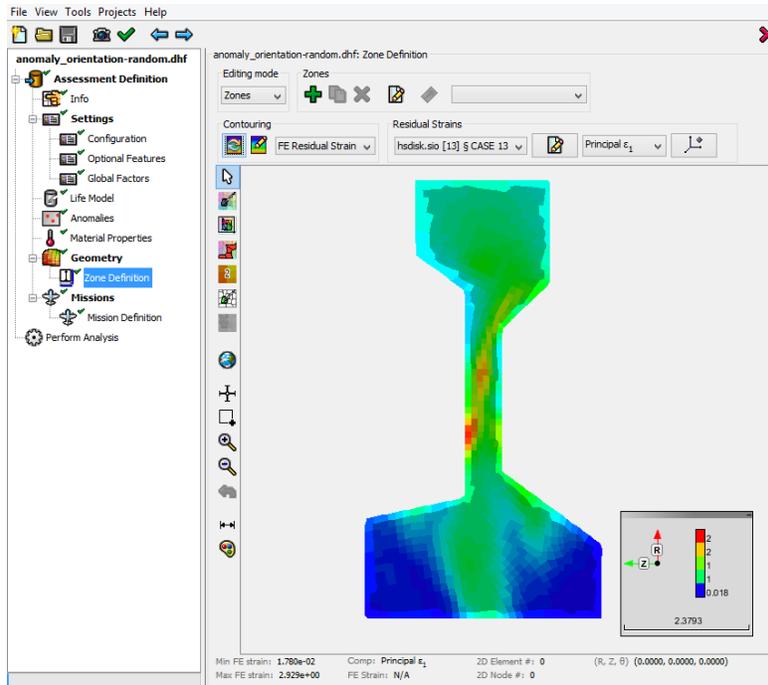
Previous versions of DARWIN include a six degree of freedom (6 DOF) anomaly model that enables users to define the dimensions and orientation of an anomaly in the form of a 3D ellipsoid. A capability was previously introduced in DARWIN 8.1 that enabled the user to import 2D FE residual strain results (such as those generated by the DEFORM software) for use in anomaly orientation computations. A separate anomaly orientation module is provided that enables the user to specify the relationship among residual strain and anomaly orientation. By default, the module aligns the longest dimension of an anomaly with the direction of maximum principal residual strain at the selected location.

New capabilities have been introduced in DARWIN 8.2 to define, process, and visualize multiple variations of residual stresses associated with modeling random residual stress in DARWIN. The user provides residual stress files containing one or more sets of residual stress results from MPS software. Each result set or “data sample” is based on a unique combination of manufacturing process variables. Users can select multiple residual stress files and define the random parameters associated with the manufacturing process input variables (Fig. 22). The user can view grain size contours associated with each residual stress result set (Fig. 23).

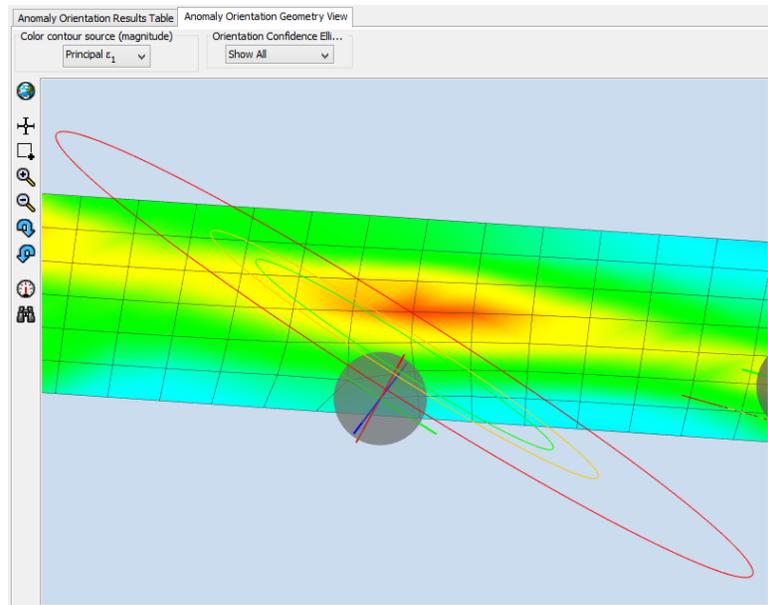
During probabilistic life assessments, a residual stress response surface is created using the user-provided results files of residual stresses. Random values associated with the manufacturing process variables are propagated through the response surface to obtain residual stress values at each FE node. The residual stress values are passed to the anomaly orientation module and are used to compute the 6 DOF anomaly orientation. The DARWIN GUI provides visualization of 6 DOF anomaly orientations in the crack growth plane based on residual strain values (Fig. 24).



**Figure 22: The anomaly orientation capability enables users to select multiple residual strain results files and to define the random parameters associated with the manufacturing process input variables.**



**Figure 23: DARWIN 8.2 enables users to view residual strain contours associated with multiple FE residual stress results from manufacturing process software such as DEFORM.**



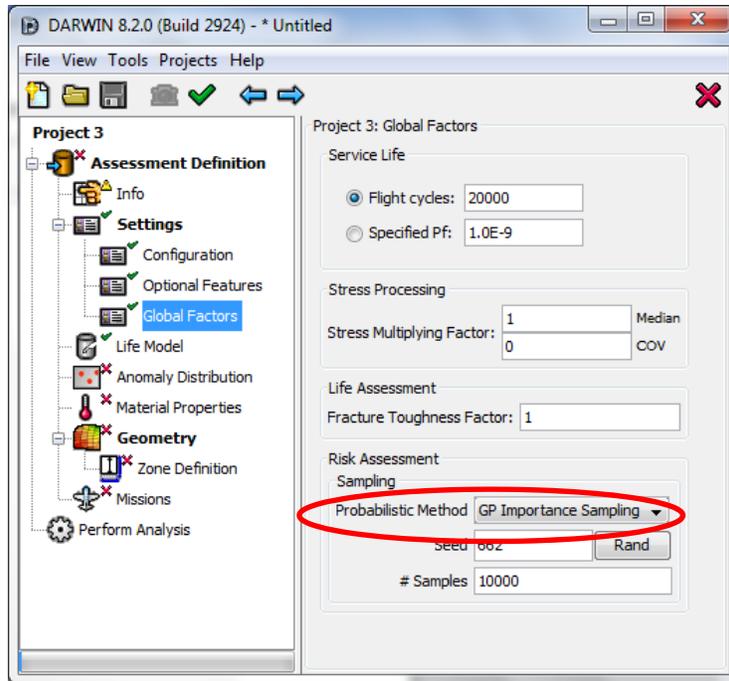
**Figure 24: DARWIN 8.2 provides visualization of 6 DOF anomaly orientation in the crack growth plane based on random FE residual strain values from DEFORM.**

## **Corrective Actions**

In Advisory Circular 39-8, the FAA provides possible corrective actions for fleets that exceed the target risk, including disk replacement and additional depot inspections. Enhancements to the DARWIN Fleet Assessment Module (FAM) now enable users to specify disk replacement for an entire fleet. Disks in service may be replaced by new disks with completely different geometries. The FAM places new disks in service based on an associated schedule for the corrective action. An additional execution of DARWIN is then required for disks associated with the corrective action. The FAM combines risk results from previous and new runs according to the disk replacement schedule.

## **GP Importance Sampling**

Previous versions of DARWIN include an importance sampling algorithm that uses an advanced numerical integration scheme to compute the probability of fracture without inspection. This approach reduces the speed of risk assessments relative to Monte Carlo simulation, but unfortunately remained limited to a few random variables. DARWIN now includes nearly a dozen possible random variables, and additional random variables are planned for future releases. DARWIN 8.2 introduces a new probabilistic method, Gaussian Process (GP) importance sampling (Fig. 25), which is computationally efficient and expandable to multiple random variables. GP importance sampling predicts the probability of fracture without inspection using a Gaussian process response surface fit of fatigue crack growth life as a function of initial crack size, stress scatter, and life scatter. The GP importance sampling method provides computational efficiency that is comparable to the previous numerical integration-based approach. It is currently limited to initial crack size, stress scatter, and life scatter, but will be expanded to support additional random variables in the future.

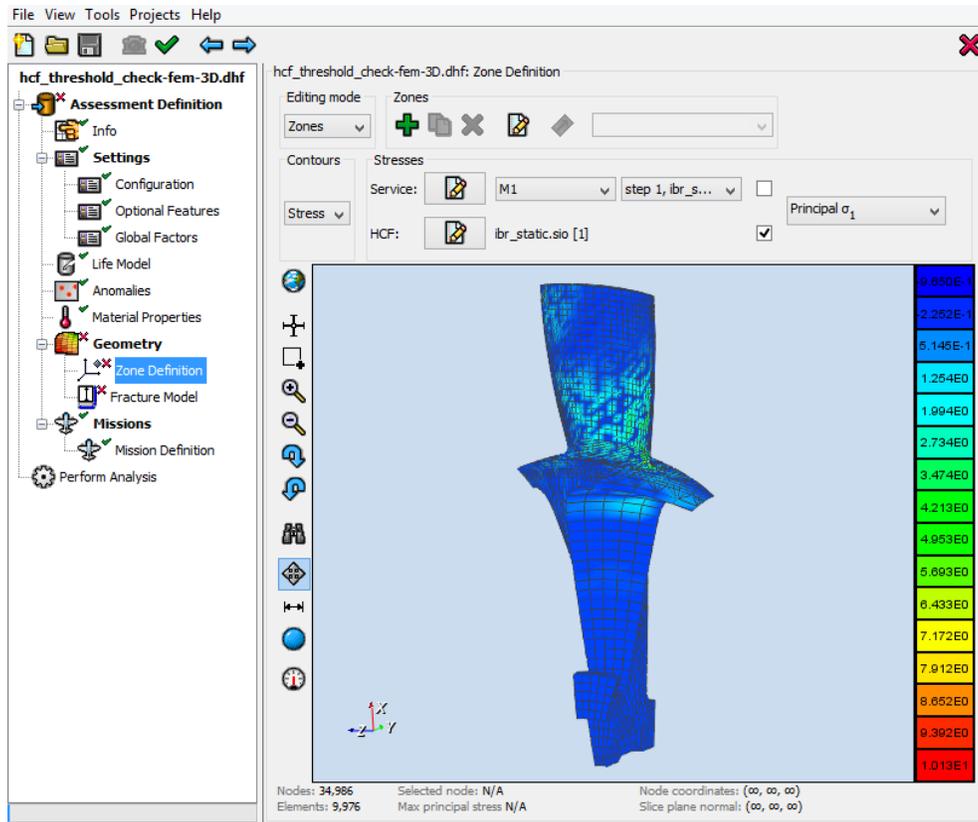


**Figure 25: DARWIN 8.2 includes a new GP Importance Sampling probabilistic method that is computationally efficient and expandable to many random variables for use in future DARWIN versions.**

## High-Cycle Fatigue (HCF) Stresses from FEM

High cycle fatigue (HCF) represents a limit state for fatigue crack growth driven by vibratory stresses. In earlier versions of DARWIN, users provided HCF stress intensity factor threshold values in the material properties file, and HCF stress values in each zone via manual input. An HCF threshold check was performed during fatigue crack growth analysis, and the corresponding life limit was reached when the HCF stress intensity factor exceeded the threshold value.

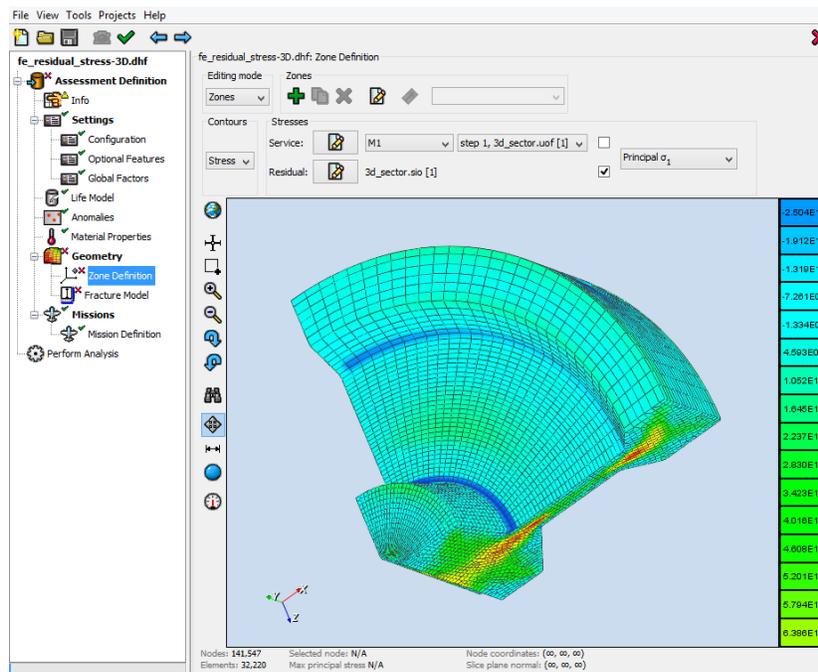
DARWIN 8.2 now enables users to import HCF stress values directly from FE models. This improvement streamlines the definition of HCF stresses among multiple zones and should lead to improved life predictions and risk assessments where HCF is a dominant fatigue mechanism. HCF stress values are automatically set at the crack location by DARWIN based on the FE input. DARWIN 8.2 has been enhanced to support user visualization (Fig. 26) of HCF stresses as well.



**Figure 26: HCF stresses can be imported from FE results directly and visualized in DARWIN 8.2.**

## 3D FEM Residual Stress

Residual stresses from forging, quenching, and other manufacturing processes can influence fatigue crack growth in components subjected to applied loading cycles. Previous versions of DARWIN provided the capability to import residual stress information from 2D FE models and to include this information in crack growth analysis. These residual stress values were superimposed onto the service stresses for analysis of life and risk. In DARWIN 8.2, this capability was extended for 3D applications where the residual stress information is imported from 3D FE results files. DARWIN 8.2 also provides an improved user interface (Fig. 27) to visualize residual stresses in 3D FE models.

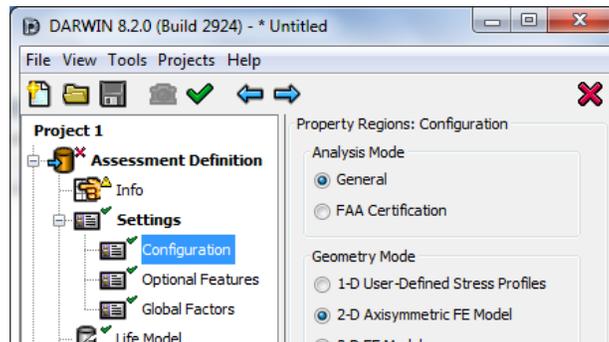


**Figure 27: DARWIN 8.2 enables users to import 3D FE residual stresses for use in life predictions and risk assessments.**

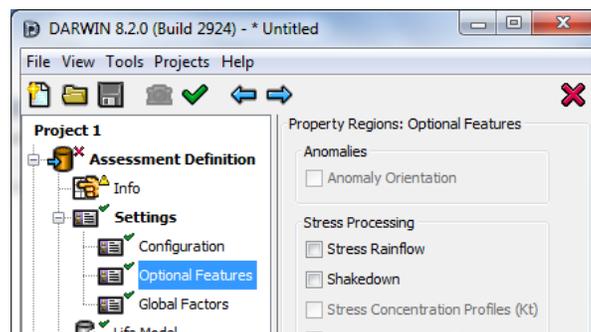
## GUI Settings Menu Modifications

In previous versions of DARWIN, users specified general analysis parameters via a single menu window. Many new features are planned for upcoming versions of DARWIN, and the associated general parameters will no longer fit in a single menu window. In addition, several general parameters were located in various submenu windows or were otherwise hidden from view. To address these issues, the GUI settings menu in DARWIN 8.2 was restructured to provide three new menu windows (Configuration, Optional Features, and Global Factors) for user input of general analysis parameters.

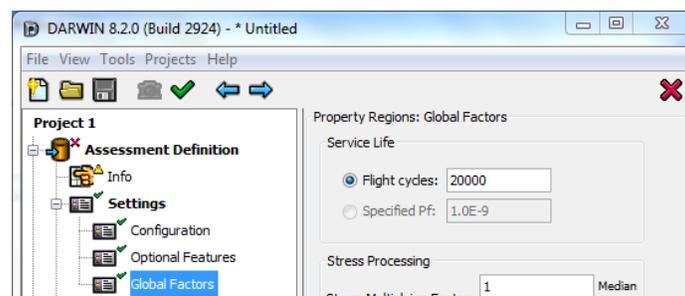
The Configuration menu window (Figure 28) contains high-level project options that alter the availability of features that are provided in other menu windows. The Optional Features menu window (Figure 29) contains activation buttons for optional features (i.e. capabilities that are not required for an analysis). When an optional feature is disabled, the input fields associated with it are hidden or disabled, which greatly simplifies the data entry task. The Global Factors menu window (Figure 30) provides a single location for input parameters that apply to the entire component.



**Figure 28: The new “Configuration” menu window provides high-level project options that affect the availability of optional features in other menu windows.**



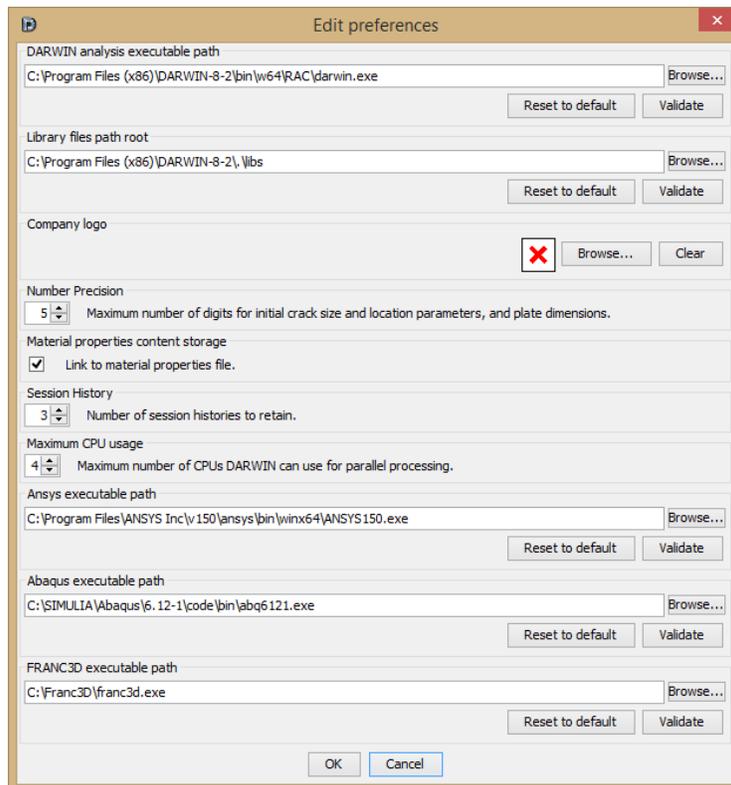
**Figure 29: The new “Optional Features” menu window controls DARWIN optional features.**



**Figure 30: The new “Global Factors” menu window provides a centralized location for input parameters that apply to the entire component.**

## Material Properties File Link

In previous releases of DARWIN, the data in the material properties file was imported directly into the DARWIN input file by default, and the material properties file was not used during execution of the analysis. DARWIN 8.2 now provides an option to obtain material properties directly from material properties files during execution rather than storing them in the DARWIN input file. This feature is an optional configuration setting (Fig. 31) that directs the user interface to store the file path when material properties data is imported. The analysis obtains material properties directly from the linked file.



**Figure 31:** Users preferences can be set to link to material properties files rather than import the material properties into the DARWIN input file.