DARWIN® 8.0 Release Notes

January 2014

Southwest Research Institute®

Summary of New Capabilities

DARWIN 8.0 includes the following new features:

- Optimal Autozoning
- Crack Growth Retardation Capability
- Bivariant Surface Crack at Off-Center Hole Feature (SC29)
- Residual Stress Enhancements
- Additional Temperature Option for Thermo-Mechanical Fatigue
- Support for Non-Hoop Stress Planes
- Crack Propagation Module
- Autoplate Enhancements
- HDF5 File Format
- File-Based License Manager

Optimal Autozoning

In the previous version of DARWIN, an initial autozoning capability was introduced for inherent anomaly materials in which a zone was placed at each finite element in a 2-D axisymmetric finite element model. This approach provided a robust risk solution with relatively long computation times, particularly for models with large numbers of finite elements. In DARWIN 8.0, the autozoning capability was enhanced to enable multiple finite elements in each zone and to identify the optimal placement of finite elements in the zones to minimize the total number of zones required for a converged risk estimate. Initial testing has confirmed that the number of zones (and associated computation times) can be dramatically reduced using the optimal autozoning algorithm. For example, as shown in Fig. 1, risk convergence was achieved with a relatively small number of zones for the test case described AC 33.14-1. The optimal placement of finite elements associated with the converged solution for the AC test case is shown in Fig. 2. The number of zones required for risk convergence is dependent on the target disk risk and a convergence threshold, both of which may be adjusted by the user. The user may also specify a maximum number of zones to terminate the analysis if needed. **Note**: The optimal zoning feature does not currently provide treatment for in-service inspections. This will be addressed in future versions of DARWIN.

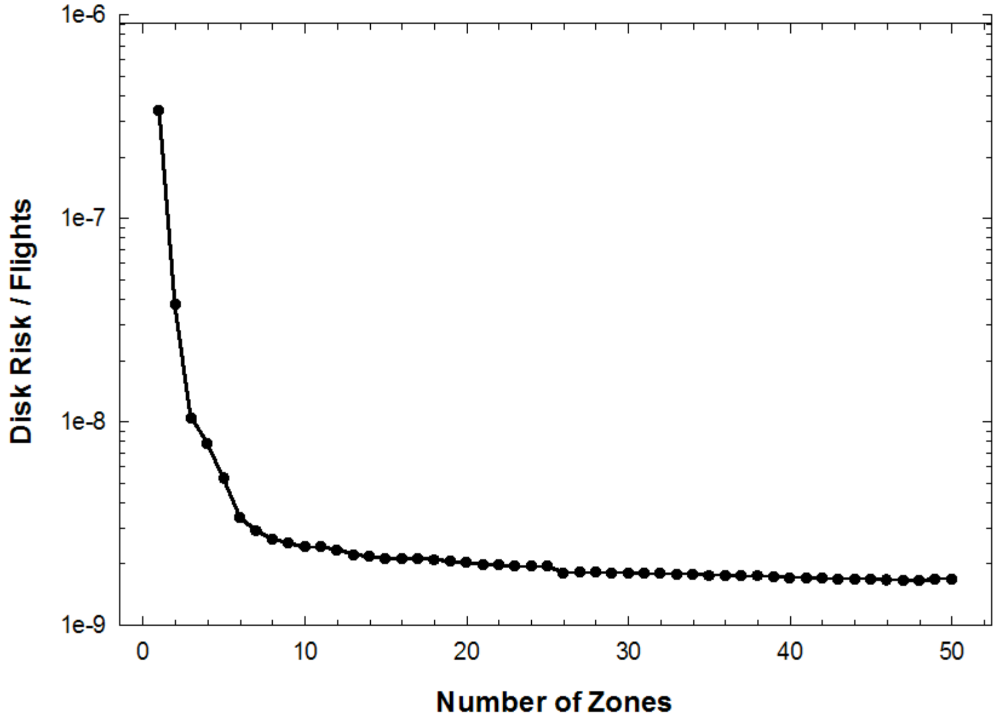


Figure 1. When optimal autozoning is used, risk convergence for the AC 33.14-1 test case is achieved with a relatively small number of zones.

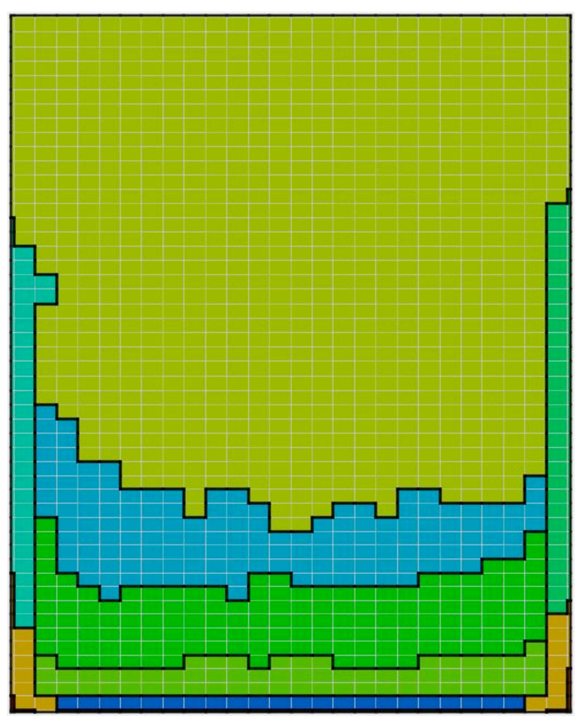
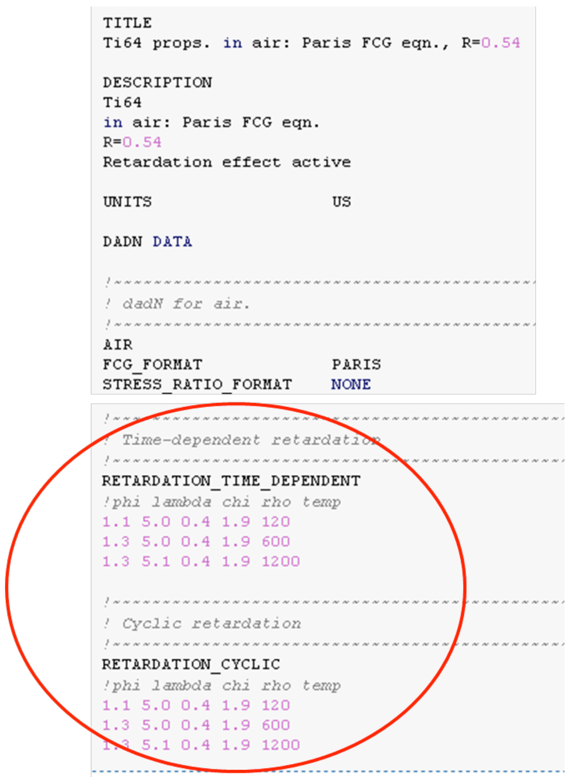


Figure 2. Optimal placement of finite elements associated with optimal autozoning for the AC 33.14-1 test case.

Crack Growth Retardation Capability

DARWIN 8.0 includes a new capability to provide treatment for overload crack growth retardation effects. This feature is based on a modified Willenborg retardation model proposed by Van Stone and Slavik (ASTM STP 1389) that utilizes a residual stress intensity factor to determine the effective stress ratio associated with load interaction. The new feature enables the analyst to include crack retardation effects for both cycle- and time-dependent crack growth life and risk assessments. The DARWIN material properties data file was enhanced to enable user specification of parameters associated with the time-dependent and cyclic crack growth retardation feature, shown in Fig. 3.



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TITLE
Ti64 props. in air: Paris FCG eqn., R=0.54

DESCRIPTION
Ti64
in air: Paris FCG eqn.
R=0.54
Retardation effect active

UNITS                   US

DADN DATA

!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
! dadN for air.
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
AIR
FCG_FORMAT              PARIS
STRESS_RATIO_FORMAT     NONE

!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
! Time-dependent retardation
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
RETARDATION_TIME_DEPENDENT
!phi lambda chi rho temp
1.1 5.0 0.4 1.9 120
1.3 5.0 0.4 1.9 600
1.3 5.1 0.4 1.9 1200

!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
! Cyclic retardation
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
RETARDATION_CYCLIC
!phi lambda chi rho temp
1.1 5.0 0.4 1.9 120
1.3 5.0 0.4 1.9 600
1.3 5.1 0.4 1.9 1200
```

Figure 3. The DARWIN material properties data file was enhanced to enable user specification of parameters associated with the time-dependent and cyclic crack growth retardation feature.

Bivariant Surface Crack at Off-Center Hole Feature (SC29)

A new bivariant stress intensity factor solution (SC29) is available for a semi-elliptical surface crack at an off-center hole (Fig. 4). The SC29 solution can be used at locations where the stress gradient varies significantly in more than one direction. For univariant stress fields, the existing DARWIN surface crack at an off-center hole solution (SC18) can be used. SC29 is available for the assessment of hole features in the 1D and 3D surface damage analysis modes.

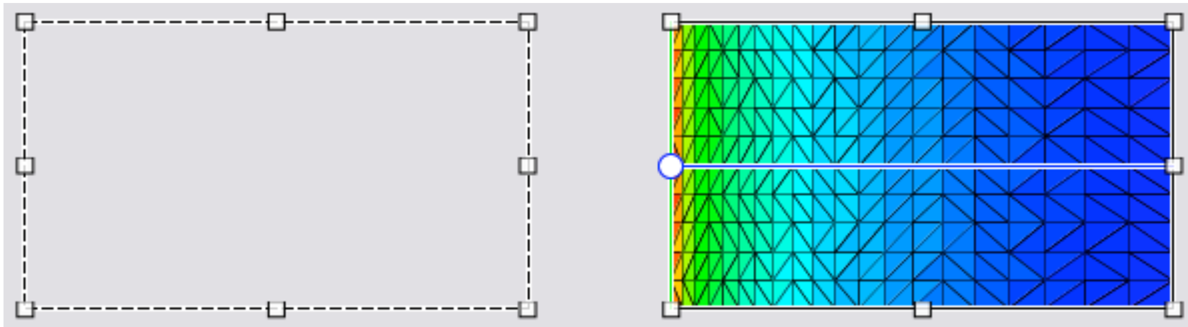

Figure 4. A new bivariant stress intensity factor solution (SC29) is available for a surface crack at an off-center hole.

Residual Stress Enhancements

A residual stress feature was previously implemented in DARWIN for modeling residual stresses associated with surface treatments in 2D finite element models that was limited to surface crack types (SC17). In DARWIN 8.0, this feature has been extended to the remaining univariant crack models associated with 2D finite element models, including EC05, CC11, and TC15 (Fig. 5). For crack growth life and risk assessment computations, the residual stresses are combined directly with service stresses using superposition. Residual stress profiles can be applied directly to 2D finite element models.

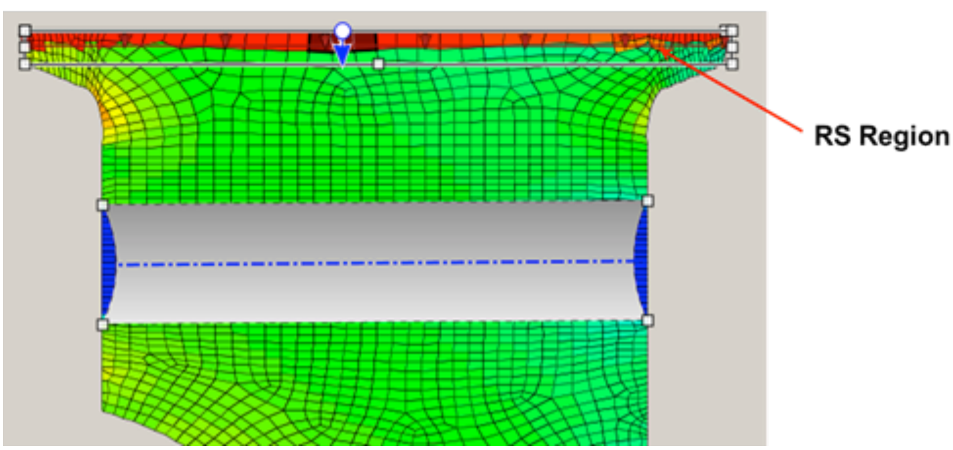

Figure 5. The residual stress feature in DARWIN 8.0 supports all univariant crack types associated with 2D finite element models, including SC17, EC05, CC11, and TC15.

Additional Temperature Option for Thermo-Mechanical Fatigue

AC 33.70-2 provides design guidelines for treatment of crack propagation under out-of-phase temperature and stress profiles in which the temperature is based on either (a) the temperature at the maximum stress in each cycle, or (b) the maximum temperature during the flight. Previous versions of DARWIN included the option to specify the temperature at the maximum stress in each cycle. In DARWIN 8.0, a new thermo-mechanical fatigue (TMF) option was introduced that enables crack propagation assessment based on the maximum temperature during the flight (Fig. 6).

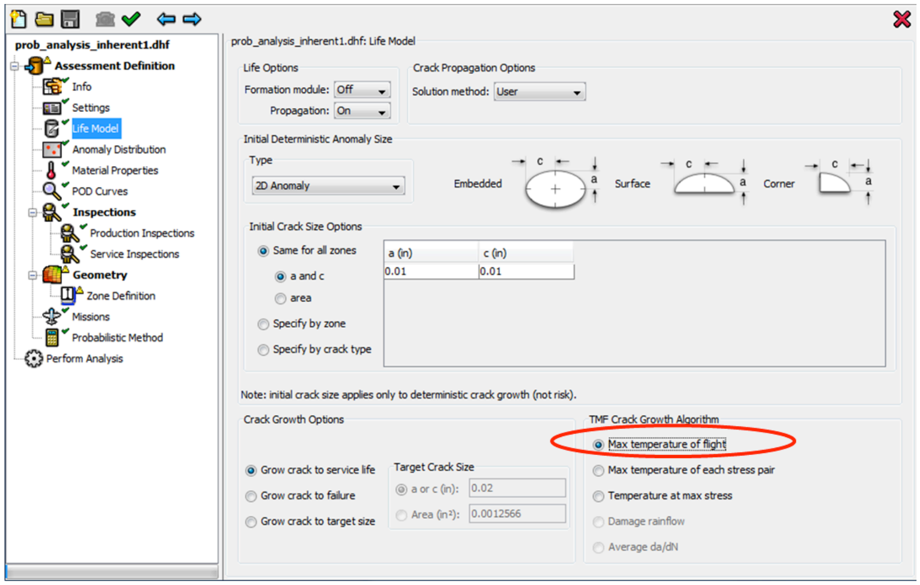

Figure 6. A new thermo-mechanical fatigue option was introduced In DARWIN 8.0 that enables crack propagation assessment based on the maximum temperature during the flight.

Support for Non-Hoop Stress Planes

In previous versions of DARWIN, fracture analysis was limited to hoop, axial, and radial planes for 2D axisymmetric models, and visualization was limited to hoop planes. DARWIN 8.0 includes a new capability to define fracture models in general non-hoop stress planes (including maximum principal stress planes) for 2D axisymmetric finite element models. This ensures that the analysis is performed for the life-limiting orientation. For non-hoop stress planes, the fracture plate is displayed as a single line that is coincident with the fracture plate stress gradient (Fig. 7). The DARWIN auto-modeling algorithms (autoplate, life contours, autozoning) were enhanced to support non-hoop stress planes, in which the maximum principal stress plane is used as the default non-hoop stress plane. This feature is currently limited to univariant SIF solutions in the 2D inherent analysis mode (i.e., EC05, SC17, and CC11).

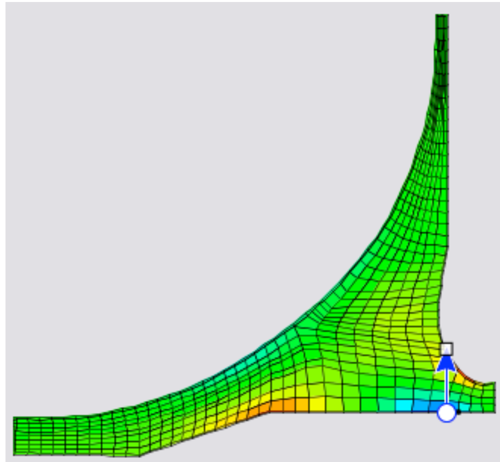

Figure 7. DARWIN 8.0 provides support for non-hoop stress planes in which the fracture plate is displayed as a single line that is coincident with the stress gradient.

Crack Propagation Module

DARWIN 8.0 includes a new user module that enables users to link an external crack propagation computer program with DARWIN (Fig. 8). When this option is enabled, the default crack propagation module *Flight_Life* is replaced by the user module, and fatigue crack growth life computations are performed via the user-supplied external crack propagation computer program.

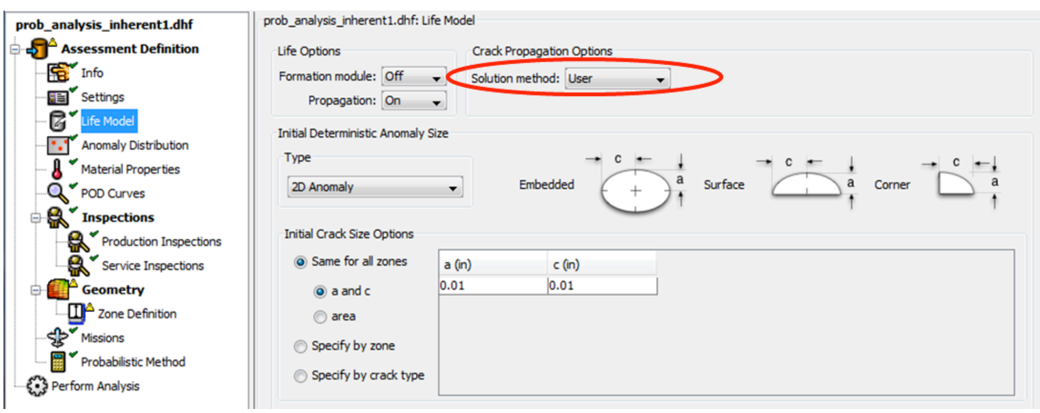

Figure 8. DARWIN 8.0 includes a new user module that enables users to link an external crack propagation computer program with DARWIN.

Autoplate Enhancements

In previous versions of DARWIN, the user had two options for creating fracture plates: *Autoplate* and *Create Plate*. *Autoplate* generates a ready-to-use plate via the DARWIN autoplate algorithm, and *Create Plate* generates a simple plate that required user manipulation. In DARWIN 8.0, these two buttons were combined into a single *Create Plate* button that builds plates using the autoplate algorithm. The user can adjust the resulting plate if desired. In rare instances in which autoplate execution fails, the plate is generated using the previous *Create Plate* algorithm. Plate information is stored in the DARWIN input file (*.dhf) and provided in the DARWIN output file (*.out) in the form of a table (Fig. 9).

Table of Fracture Mechanics Plate Sources

		Reference Load Case		
Zone ID	Generator	Mission	Load Case ID	Stress Plane
1	AUTOPLATE	1	2	HOOP
2	AUTOPLATE	1	4	AXIAL
3	AUTOPLATE	1	1	MAX_PRINCIPAL_STRESS
4	USER	1	1	HOOP
5	USER	1	2	HOOP
6	AUTOPLATE	1	2	HOOP

Figure 9. Fracture plate information is now provided in the DARWIN *.out file.

HDF5 File Format

In previous versions of DARWIN, XML-formatted files were used for storage of input and results data. This format was adequate for the small amount of data typically associated with routine risk assessments involving univariant crack types and small numbers of zones, finite elements, and load steps. However, DARWIN capabilities have been expanded in recent years to include data-rich features such as bivariant crack types and autozoning. In addition, as computer speeds increase, analysts have been developing finite element models with significantly more elements and load steps. All of these factors have contributed to increases in file sizes that have become difficult to manage using the XML file format in previous DARWIN versions.

To resolve these issues, a new file format called HDF5 was recently implemented in DARWIN. HDF5 is a binary hierarchical file format that was specifically designed for complex high volume data. It supports direct random access to specific locations within a file without the need to load the entire file into memory, which significantly reduces memory requirements. It is mature technology with over twenty years of development history, and it is actively developed and maintained by the HDF Group at the University of Illinois at Urbana-Champaign. A single-file system has been adopted in which the analysis input and output data files have been combined into a single HDF5-formatted file (*.dhf).

HDF5 organizes data in a tree-like, hierarchical structure that is similar to the data structure used for XML-formatted data. This structure makes it convenient to navigate large files with complex data. HDF5 files can be easily viewed and edited using a free open-source tool called HDFView which provides capabilities to add, delete, copy, and paste data. The DARWIN GUI was recently enhanced to include the HDF5 viewer for display and editing of HDF5-formatted files (Fig. 10). The tabular data in HDFView are compatible with Microsoft Excel, which enables the analyst to directly copy tabular data into Excel spreadsheets for post-processing.

Use of the HDF5 file format in DARWIN has significantly reduced the amount of computer memory required for execution, particularly for large files. When the HDF5 format is used, memory requirements are based on the amount of data that are used rather than the amount of data that are present in the input files. Therefore, it is anticipated that DARWIN will be able to support even larger file sizes in the future without a substantial increase in memory use. In general, file sizes will actually become smaller when the HDF5 format is used due to the relatively compact binary format associated with HDF5.

The initial DARWIN implementation has been focused on reading and writing HDF5-formatted files using the existing architecture that was developed previously for XML-formatted files. It provides a solid and efficient framework for data access and storage that has reduced memory requirements and enabled systematic verification. However, HDF5 provides additional capabilities that have the potential to reduce computation time. Future implementation will focus on performance improvements to take advantage of these powerful capabilities.

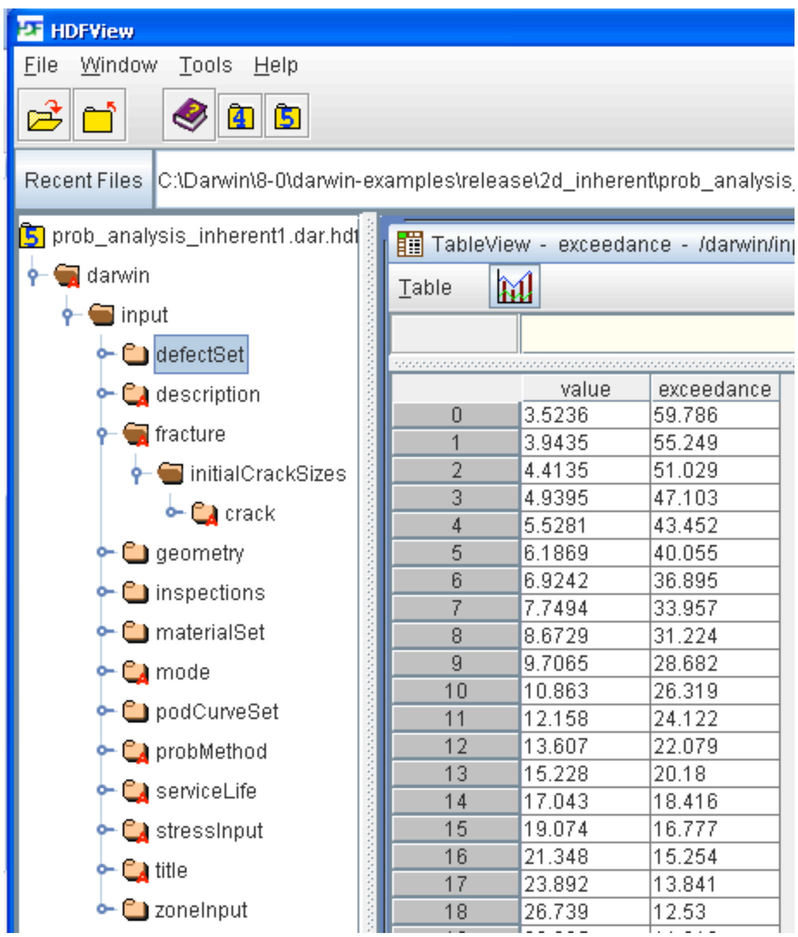

Figure 10. The DARWIN GUI provides a new text editor that enables display and editing of HDF5 files.

File-Based License Manager

In DARWIN 8.0, the legacy key-based licensing manager was replaced by a file-based licensing manager called FlexNet Publisher (Flexera Software). FlexNet Publisher uses a file containing licensing details to validate usage rights of the DARWIN application. More information regarding this new feature is provided in the DARWIN User's Guide.

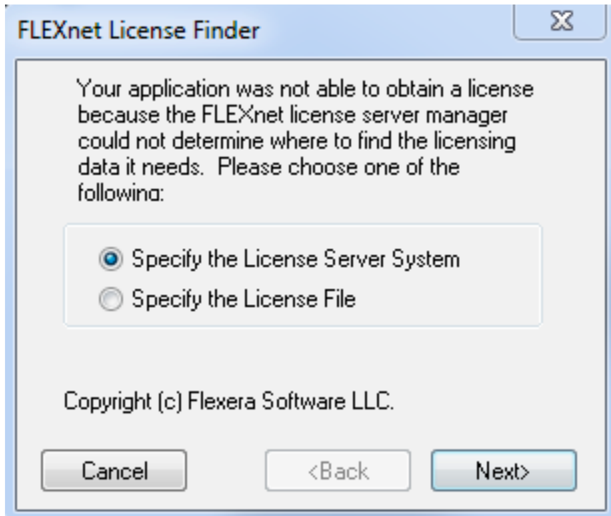

Figure 11. The FlexNet Publisher licensing manager uses a license file to validate usage rights of the DARWIN application.