

APPENDIX A

QUESTIONNAIRE

Contact Name: *P-61 Black Widow*

Name:

Organization:

Please provide information about the analyses completed:

1. Analysis Software (name and version)
 - a. FEA software (if applicable): *MSC Marc 2019*
 - b. Crack growth software: *AFGROW 5.3.5.24*

2. FEA Model Setup (if applicable)
 - a. Describe the boundary conditions utilized in the FEMs, to include applied loads and constraints

Quarter planar (2D) model with symmetry boundary conditions along the X and Y axes (fastener and coupon). The remote load is applied as uniform stress at the far edge. The quarter model size is 1.2 in X 4 in. 2D solid plane strain elements were used.

- b. Describe the methods to define and control the crack front shape and control meshing along the crack front

The FE model was used to determine stress distributions due to the interference fit and due to the pin restraint. No crack was assumed in the model.

Interference Fit Modeling

- c. Describe the methods used to characterize and incorporate the effect of the IFF.

A thermal contraction/expansion analogy was used in a multi-step multi-body contact analysis. First, the fastener was shrunk in a linear step by applying a negative ΔT , then it was expanded by releasing this ΔT . Contact was activated for the second step onwards. Generic steel properties ($E = 30 \text{ Msi}$; $\nu = 0.33$) were used for the fastener. The provided properties were used for the aluminum coupon, assuming an elastic – perfectly plastic model. Plasticity was triggered by the von Mises stress reaching the provided yield value.

A stress distribution that defined the baseline state of “residual stresses” was obtained in the following manner:

- 1) Interference fit simulation was performed as described above.*
- 2) One cycle of maximum spectrum stress to zero loads was applied. The combination of high applied loads (y direction) and compressive radial interference fit stresses (x direction on the crack plane) triggered plasticity, causing residual stresses.*

This stress distribution was assumed constant and independent of the remote load. It was incorporated in AFGROW as a 1D residual stress distribution.

Another stress distribution was obtained to isolate the effect of the remote load and interference fit fastener (filled hole restraint) from the complete state of stress in the following manner:

- 1) The residual stress effect obtained above was subtracted from the total stress distribution obtained at the max remote load.*

This stress distribution was assumed scalable with the remote load. It was incorporated in AFGROW as a 1D Beta correction through the Normalized Stress approach applied to a corner crack at a hole. It was normalized with respect to the open hole stress distribution obtained from the same FE mesh.

The two stress distributions were superposed by AFGROW to obtain K values at the min and max constant amplitude spectrum loads.

- d. If the fastener effect was derived from a closed form solution, what were the assumptions of the solution. Is the solution based on empirical data or FEM correlations?

N/A

- e. If the fastener was modeled using FEA, does the model consider non-linear effects? Was multi-body contact used? If contact was used, what friction related assumptions were made?

See above. No friction was assumed. The segment-to-segment contact method in MSC Marc was used. The default values for the contact parameters were used (contact detection, bias, etc.).

3. Stress Intensity Calculations

- a. Describe the methods used to extract and calculate the stress intensities for applied remote loads

Taken care of by AFGROW as described above. Used superposition of a 1D residual stress distribution with a 1D Beta correction factor (Normalized Stress approach), applied to a Fawaz-Anderson single corner crack at a hole.

- b. Describe the methods used to incorporate the stress intensities into the crack growth code (superposition, etc.)

See above.

4. Crack Growth Predictions

- a. Describe the material model approach used for the crack growth predictions (NASGRO, tabular, etc.) and the assumptions/approach used for “threshold”, stress ratio (R) shift, and negative R behavior.

AFGROW tabular lookup, entered as provided. The R and da/dN limits were set as the extreme values provided. The ΔK threshold was calculated using the Walker equation ($2.184444 \text{ ksi in}^{0.5}$)

- b. What growth increment was utilized between stress intensity calculations?

Cycle by cycle calculation (beta and spectrum)

5. Provide any additional details that may be pertinent to the analyses completed



