A Life Prediction Algorithm Implemented in P3 Using PCL

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ABSTRACT

A life prediction methodology is implemented in P3 through a computer program, Probable Cause, written in Patran Command Language (PCL). The software uses finite element analysis data, and probabilistic material parameters to predict the component life and probability of survival for the analysis model. Probable Cause is imbedded in P3 and is accessed through a graphical user interface called from the main menu bar.

The theory in Probable Cause is briefly outlined in this paper and its use is demonstrated with a finite element analysis of a jet engine turbine disk. The usefulness of PCL in accomplishing a task of this nature is shown and the lessons learned in the development process are discussed.

Introduction

Key to the design process of a structural component is the determination of an expected minimum service life for the component, and the probability of its current design failing before the design life is achieved. Establishing such probabilities through experimental means are likely to be time intensive, cost prohibitive, and could preclude evaluation of several different prototypes in an attempt to optimize a specific design. Because of these factors, a numerical approach to evaluate component survivability has a number of advantages over an experimental method.

One such approach incorporates stress results from finite element analyses along with two probabilistic material parameters to predict a relative probability of survival for each element in the model and ultimately the entire model. This method, developed by Zaretsky[1], relates element centroidal stresses and volumes, along with the material stress life exponent, and the Weibull slope of the material modulus in several equations to compute life and survivability predictions for the finite element model.

The nature of this work is ideally suited for implementation into P3 using the Patran Command Language or PCL. PCL was used to develop a graphical user interface selectable from the main Patran menu bar. Once the necessary information is input into the interface, the program retrieves the stress data, already in the Patran database, performs the computations, and writes the results back to the database as scalar data for post processing. Additional code is currently being implemented enabling automatic generation of various X-Y plots to further quantify the statistical data.

PCL is a powerful programming language which can be applied to wide variety of engineering problems in conjunction with Patran. Only one such problem is examined here. This paper outlines the process followed to complete this exercise and demonstrates the advantages of using PCL to streamline an otherwise time consuming process. An example probabilistic analysis is presented in order to provide a complete picture of what has been accomplished with this PCL program.

Methodology

It is the intent of this paper to discuss the implementation of this particular method and not to present detail of the theory itself. A brief background will be presented here, and the interested reader can pursue additional information through the references listed.

Zaretsky [1] presented a method for calculating the local probability of failure within any component's stressed volume and furthermore within the entire component itself. August and Zaretsky [2] extended this method by developing a technique to predict component life and survivability based on finite element stress analysis. These predictions are computed using the following equations:

$$L = L_{ref}\left[\frac{\tau_{ref}}{\tau}\right]^{C}\left[\frac{V_{ref}}{V}\right]^{1/e}$$

and,

$$S = S_{ref}^{\left(L_{ref}/L\right)^{e}}$$

Where:
- L = Stress cycles to failure for given element
- τ = Element centroidal stress (usually maximum shear)
- v = Volume
- c = Stress life exponent
- e = Material Weibull slope
- S = Probability of survival for given element

Using these equations and centroidal stress results from a finite element analysis, L and S values for each element can be computed. Hence, the probability of survival for the entire analysis model can be obtained by multiplying the individual survivabilities together as follows:

$$S_{component} = S_1 \cdot S_2 \ldots S_n$$

These equations provide relative values for L and S in relation to reference values chosen from a selected element. Generally, reference values of 1.0 and .9 are assigned to the L_{ref} and S_{ref} variables respectively in the above equations. This implies a relative life of unity and a probability of survival of 90 percent for the reference element. Maximum shear stress values are normally used for τ_{ref} based on their applicability to maximum shear stress failure theory for ductile materials. A reference element can be chosen at random, however, the authors have primarily used the element with the highest resultant shear stress as a reference point. The stress life exponent and the Weibull slope are parameters specific to the material. The aforementioned references outline the rational for obtaining these values.

The simplicity of this method makes it an ideal candidate for implementation into a PCL routine to be imbedded in P3. The program, entitled Probable Cause, operates on analysis results within a P3 database and stores the life and survivability predictions as additional results files for post processing using the standard P3 tools. The capability of Probable Cause will further be expanded by taking advantage of the imbedded X-Y plotting routines in P3 to automatically generate several statistical plots of the probabilistic results.

Figure 1. outlines the general flow of Probable Cause and its primary features. Running the routine is straight forward. The user calls up the Probable Cause Parent widget from the **custom** selection, shown in Figure 2, on the main menu bar.

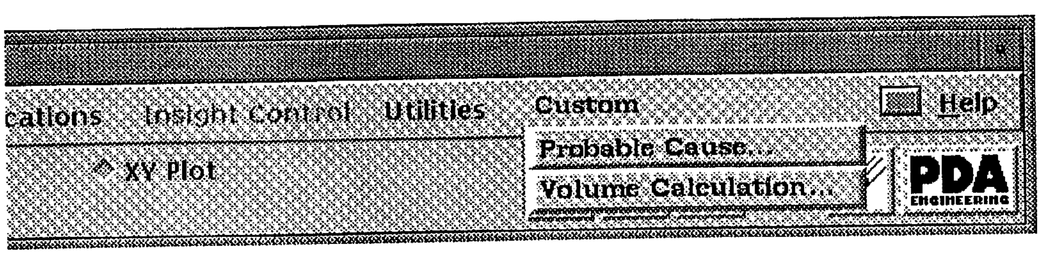

Figure 2. Probable Cause Pull Down Menu

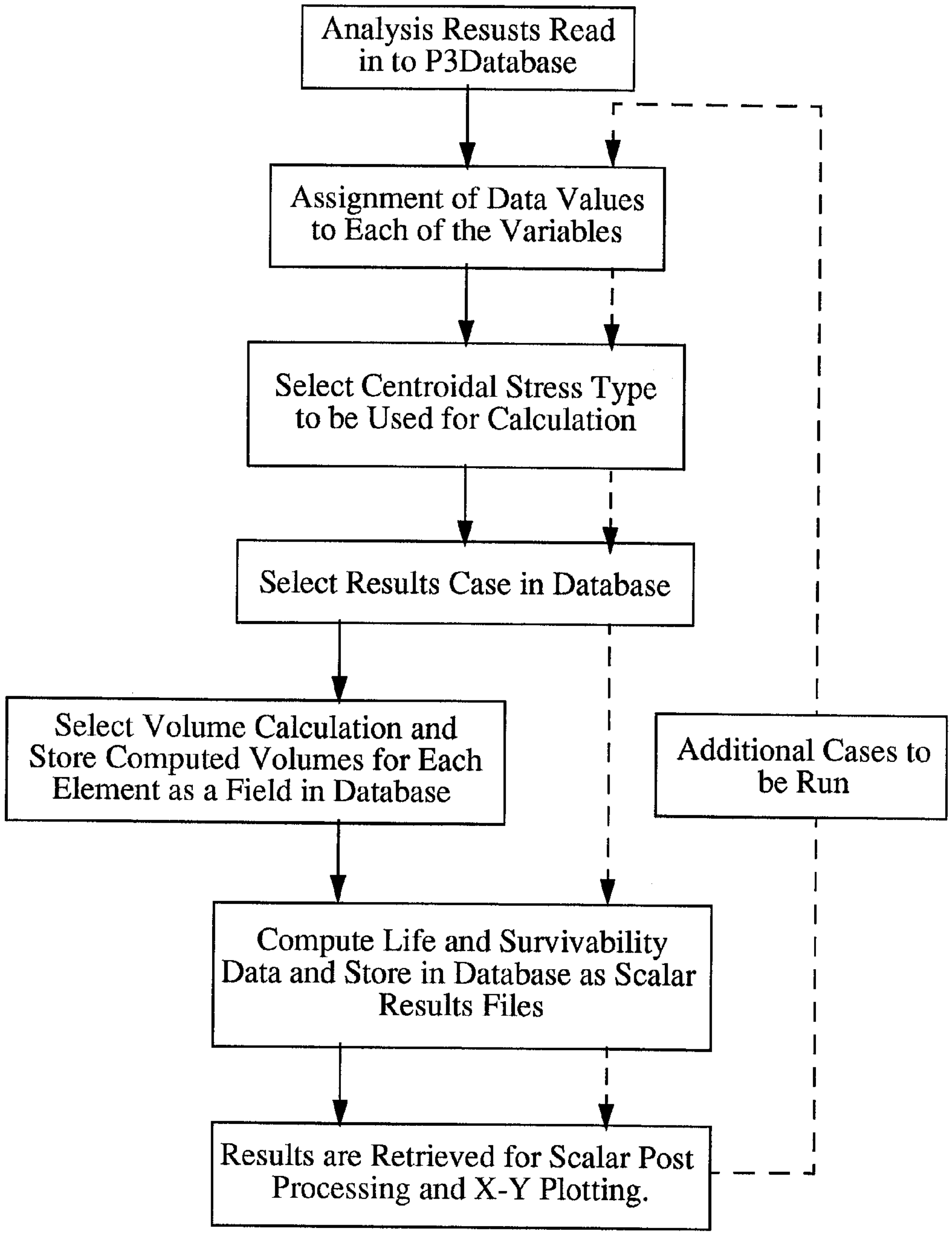

Figure 1.Probable Cause Flow Chart

Figure 3 depicts the parent form, "**Probability Analysis Form**". As mentioned previously, the element with the maximum stress value is typically used to provide the reference values for stress and volume, namely τ_{ref} and V_{ref}. Should the user wish to input specific values, selecting the "**Assign Values**" button instantiates select databoxes for τ_{ref} and V_{ref}. Several calculation parameters are set using the appropriate select databox. A result is selected using a results toolbox that is invoked with the "**Results...**" button on the parent form. This form is shown in Figure 4. Currently, Probable Cause only operates with scalar data. Vector and Tensor items are provided as place holders for future code development. Shown in the derivation box of the form is **MAXSHR**, or maximum shear. A derivation can be selected from any of 21 centroidal stress values should the user choose to experiment with the failure theory. The result case to be referenced is chosen through the "**Load Result...**" button completing the required input for the "**Results...**" button of the parent form. Upon successfully loading the requested result case the "**Calculate L & S**" button is activated. When the user presses the button to calculate L and S values, the code checks to see if the volume calculation had been performed for the model. If not, the **Volume Collation** form is called up as seen in Figure 5. There are two possible methods that can be used to compute element volume: The Vector Cross Product, and the P3 Formulation. The Vector Cross Product method

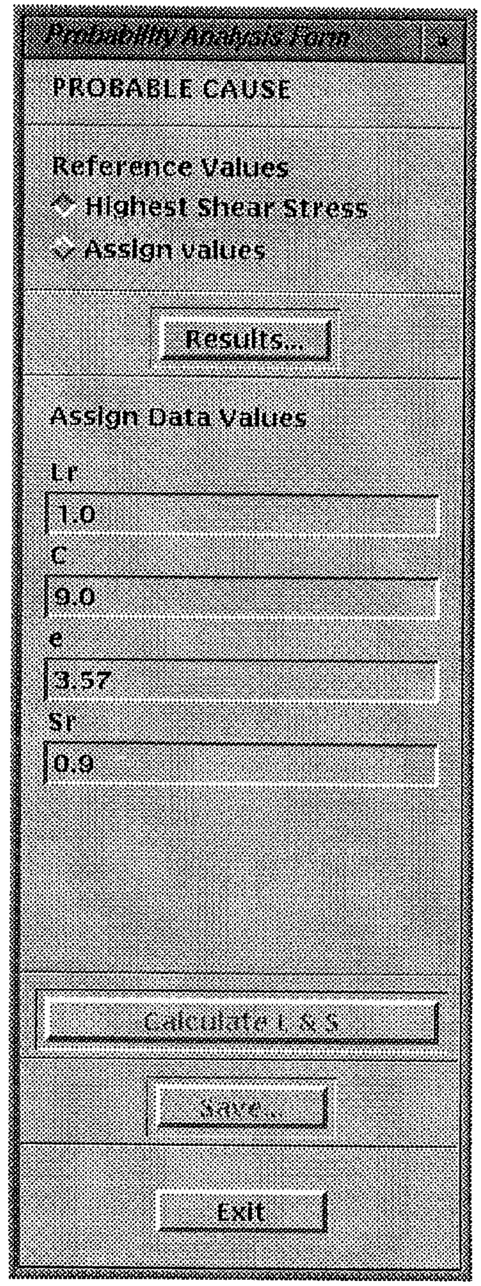

Figure 3.Probable Cause Parent Form

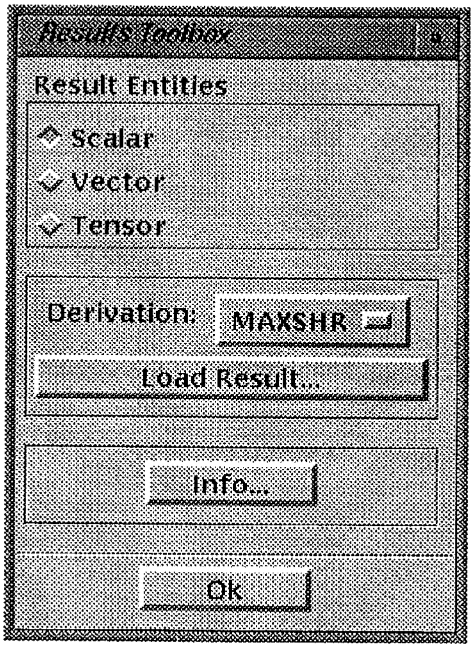

Figure 4. Results Toolbox Form

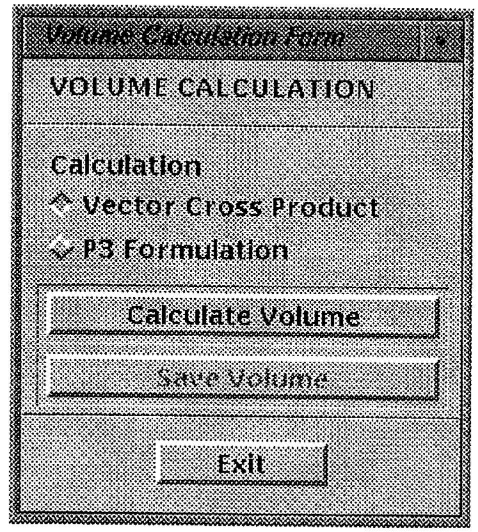

Figure 5. Volume Calculation Form

is significantly faster than using the P3 Formulation but may generate erroneous element volumes if the model has any skewed elements. The P3 Formulation, an internal routine in P3, will yield the most accurate results. For a given model, the volume only has to be calculated once unless there are changes made to the mesh Should the volume have to be computed again, the "**Volume Calculation**" form can be called from the **Custom** pick on the main menu bar. Upon Completion of a Probable Cause run, the "**Save**" button at the bottom of the parent form will become active. Clicking this will prompt the user to save the **L** and/or **S** data sets as results in the P3 database. The survivability factor for the entire model appears in the command window should the user require this. These data can be visualized using the full range of post processing tools in P3.

Currently, efforts are underway to implement a plotting capability within Probable Cause. This software will enable the user to automatically generate several statistical plots using the **L** and **S** computed for a given load case. These graphs will help the user to better understand and visualize trends and characteristics in the results.

Example Problem

As a demonstration, a linear static analysis using solution 101 with MSC/NASTRAN is performed on a jet engine turbine disk. Figure 6. shows the actual finite element model as it relates to the total geometry of the disk. Intuitively, it is expected that there will be stress concentrations at the bolt holes from centrifugal loading as depicted in Figure 7, a Von Mises Stress fringe plot.

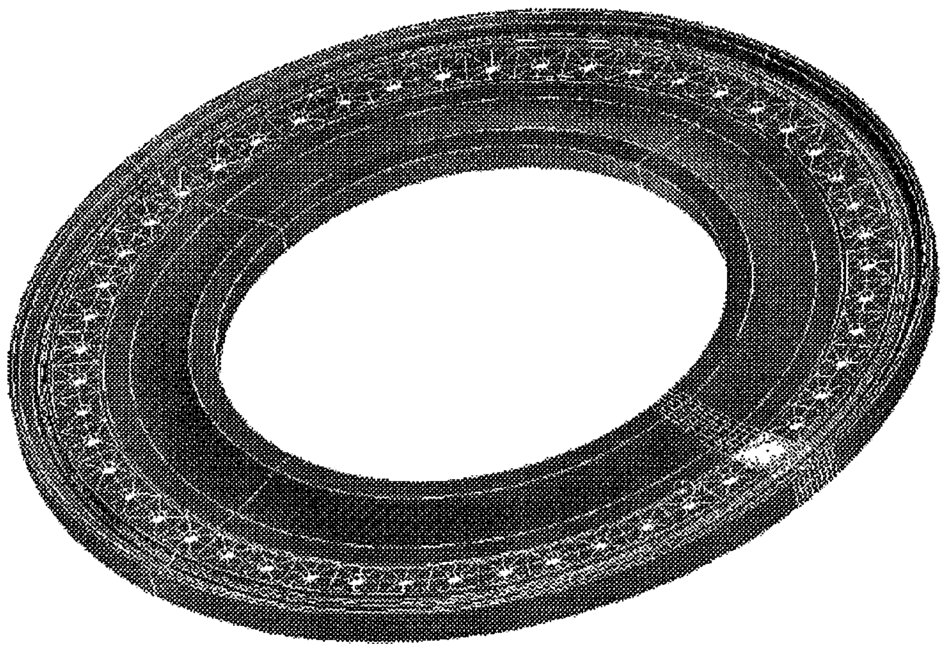

Figure 6. Geometric and Finite Element Model of Turbine Disk

Running Probable Cause and plotting the resulting data set of S values yields the fringe plot shown in Figure 8. This figure indicates a very localized region in the bolt hole area in which material failure is most likely to occur. This is consistent with what engineering judgement would tell us. It is important to note again that these results are normalized with respect to the model. In order to apply these statistical predictions to an actual component, these results must be used in conjunction with specific material and component test data. This ultimately provides valuable insight to understanding the statistical behavior of a structural component as it undergoes service loading.

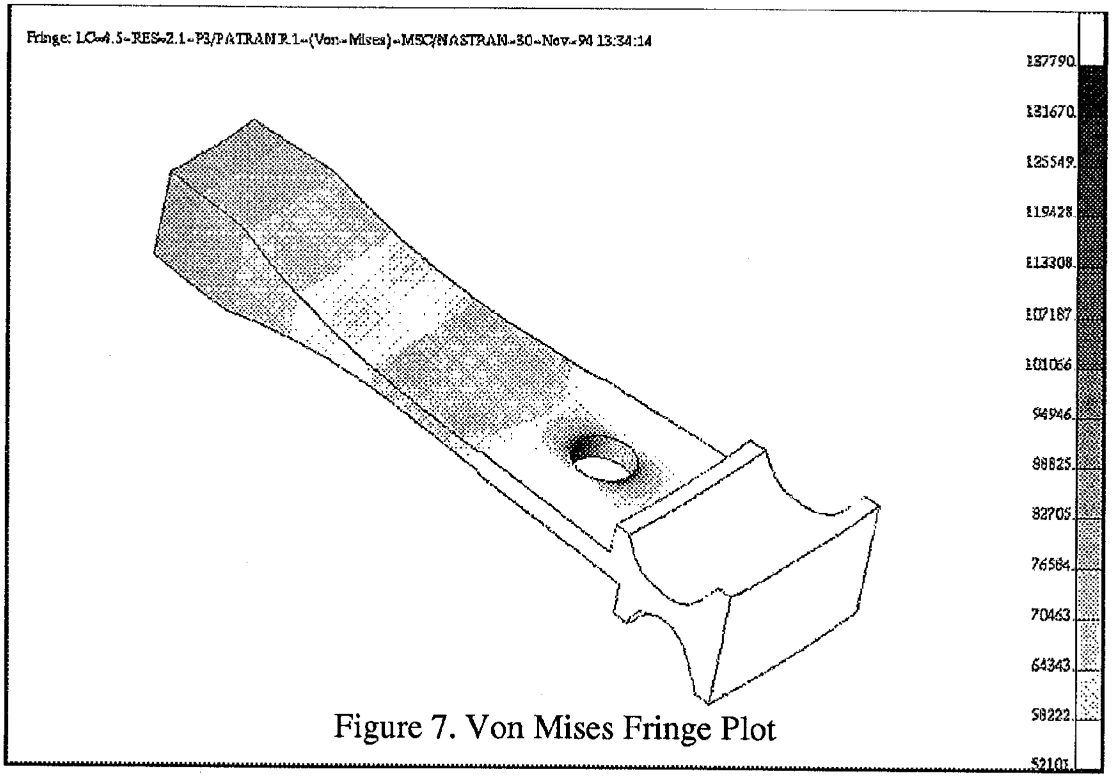

Figure 7. Von Mises Fringe Plot

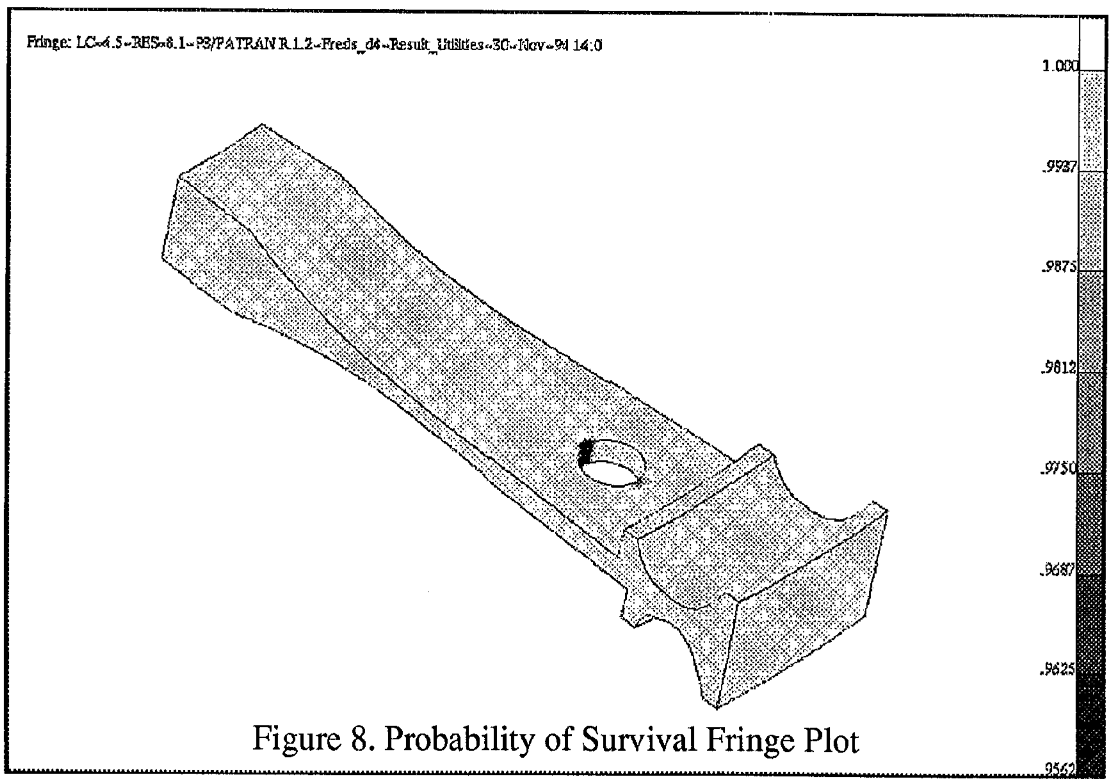

Figure 8. Probability of Survival Fringe Plot

Discussion

The above demonstrates just one way that PCL can be utilized to expand the analysts capabilities in working with P3 as well as streamline the analysis process. The authors recommended that intermediate and advanced users of P3 acquire an understanding of PCL in order to fully exploit the software's capabilities. PCL provides the user nearly full control over the entire modeling process. During the development of the Probable Cause software, there were a number of lessons learned with PCL which should be noted.

- It was found to be highly flexible language in terms of incorporating in-house code directly into P3 due to an extensive library of functions available to the programmer. Numerous plans for other PCL projects have spawned as a result of this effort.

- Weak documentation and few examples made for a steep learning curve. However, after a certain level understanding of the language was acquired, the programming tasks became relatively straight forward.

- Setting up forms proved to be one of the greatest challenges in writing the software. A toolkit to generate such forms would provide a great help to novice PCL programmers.

- Further enhancement is desired for the p3pclcomp compiler such as function checking, etc.

- Programming experience in the C language is very beneficial in using PCL. A systematic and careful approach to programming will result in a custom library of robust, reusable software.

Acknowledgments

The Authors would like to acknowledge the efforts of Erwin Zaretsky, and Richard August in providing the probabilistic methodology discussed herein.

References

(1) Zaretsky, E. V., "Fatigue Criterion to System Design, Life, and Reliability," *Journal of Propulsion and Powers*, Val. 3, No. 1, 1987, pp.76-83.

(2)August, R., and Zaretsky, E., V., "Incorporation Finite Element Analysis into Component Life and Reliability," NASA TM 104400, 1991.